LISBON SCHOOL OF ECONOMICS & MANAGEMENT
UNIVERSIDADE DE LISBOA

MASTER

ACTUARIAL SCIENCE

MASTER´S FINAL WORK

DISSERTATION

MORTALITY OF ELITE ATHLETES: AN APPLICATION TO FOOTBALL PLAYERS

INÊS FILIPA COSTA MARQUES

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SUPERVISION:

ONOFRE ALVES SIMÕES

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Abstract

The health benefits of moderate regular physical activity have been clearly demonstrated and are widely consensual. However, there is a growing debate over the potential adverse effects of strenuous physical activity, particularly at a professional level. Recent findings of cardiovascular anomalies in elite athletes coupled with the high frequency of injuries have brought some sports under increased scrutiny.

In this context, the main goal of this work is to investigate whether elite athletes live longer than the general population. After an initial review of the literature on elite athletes' mortality, a comprehensive survival analysis is applied to two populations of professional football players.

Lifespan data and specific occupational variables of Portuguese and Spanish football players, who have represented their national teams in their career, were collected from recognized publicly available sources. Each cohort is then compared to the respective standard population, using available data in the Human Mortality Database, through the estimation of standardised mortality ratios and survival curves. The years-lost method is applied to provide a time dimension measure for these elite athletes' longevity. Furthermore, the association of position on the field and the number of games with overall mortality is accessed using Cox Proportional Hazard Models. At the end, a comparison between the mortality of Portuguese and Spanish football players is carried out.

Keywords: elite athletes, mortality, longevity, standardised mortality ratio, survival curve, years-lost method, Cox Proportional Hazard Models

Resumo

Os benefícios para a saúde resultantes da prática regular de exercício físico, de uma forma moderada, estão cientificamente comprovados. Contudo, quando se trata de uma abordagem sobre atletas profissionais, cuja actividade física é muito intensa, os benefícios deixam de ser uma clara evidência, surgindo por vezes sinais de alerta para os seus possíveis efeitos adversos. Para alimentar esta controvérsia, muito têm contribuído os estudos recentes que evidenciam anomalias e doenças cardiovasculares, bem como as frequentes lesões em atletas de elite.

É neste contexto que surge o principal objectivo deste trabalho: investigar se os atletas de elite vivem mais do que a população em geral. Após uma profunda revisão literária inicial relativa à mortalidade dos atletas de elite, procede-se a uma análise de sobrevivência que tem como foco dois grupos de jogadores de futebol profissionais.

Recolheram-se dados relativos à data de nascimento e morte (se for o caso) dos jogadores portugueses e espanhóis que representaram a sua selecção, bem como de outras variáveis de interesse para o estudo. Cada grupo de jogadores é comparado com a população geral do respectivo país, usando dados disponíveis na *Human Mortality Database*, através da estimação de *standardised mortality ratios* e de curvas de sobrevivência. O *years-lost method* é também aplicado, fornecendo uma medida de longevidade dos referidos atletas de elite. Ainda é averiguado se a posição dos jogadores e o número de jogos na sua carreira afectam diferencialmente a mortalidade dos mesmos, através dos *Cox Proportional Hazard Models*. Por fim, as populações dos jogadores portugueses e espanhóis são comparadas entre si.

Palavras-chave: atletas de elite, mortalidade, longevidade, standardised mortality ratio, curva de sobrevivência, years-lost method, Cox Proportional Hazard Models

Acknowledgements

I would like to start by thanking my supervisor, Professor Onofre Alves Simões, for his indispensable support, valuable suggestions and availability. I am particularly grateful for not letting me quit the subject of the thesis when I thought I did not have sufficient information to proceed.

I extend my profound appreciation to Professor Eduardo Trigo for providing sources of data for the study.

I am also thankful to all Professors of the Master's Degree for their insightful lectures and patience for my endless questions.

I also express my gratitude to Tranquilidade for the opportunity of doing an internship, allowing the development of my actuarial skills. The attendance of the R software course was particularly helpful in the progress of the thesis. I would like to thank my colleagues of the Non-Life Actuary Department for making me feel part of the team since the beginning.

The warmest thanks go to my family. To my parents, who have equipped me with all the tools and skills to be successful in any career path I decided to follow. To my grandmother, who provided me the best place to work and the most delightful breaks. I wish you were here to celebrate one more accomplishment. To my brother for not letting me down with his good humor during the periods of low energy and motivation. To João, for the unconditional support, generosity, understanding and for always believing in me. I am fortunate to have you in my life.

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List of Abbreviations

Abbreviation	**Meaning**
ALS	Amyotrophic Lateral Sclerosis
BMI	Body Mass Index
CI	Confidence Interval
HMD	Human Mortality Database
HR	Hazard Rate
NFL	National Football League
SMR	Standardised Mortality Ratio
US	United States
YLL	Years of Life Lost

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Chapter 1 – Introduction

Nowadays, there is little doubt that regular physical exercise is beneficial for the individuals' well-being, contributing to the prevention of cardiovascular diseases, hypertension, obesity, depression and some types of cancer, such as colon, breast, and lung (Hurley and Reuter, 2011). The World Health Organization (WHO, 2010) recommends that children should spend at least 60 minutes of moderate to vigorous-intensity physical activity daily, while adults are advised to do at least 150 minutes throughout the week. For additional health benefits, people are encouraged to increase these durations and to incorporate muscle-strengthening activities.

In a study about the association between the different intensities of physical exercise and longevity, using a cohort of 13 485 men who have enrolled as undergraduates in Harvard University in the period 1916-1950, the authors conclude that greater energy expenditure is associated with lower mortality and this trend is more pronounced for vigorous activities than for moderate activities (Lee and Paffenbarger, 2000).

However, recent controversy exists regarding the potential adverse effects of repeated exposure to high levels of physical exercise, such as those required at a professional sports level.

One of the topics of current debate is the increased susceptibility of elite athletes to cardiovascular diseases. High-competitive sports may lead to physiological changes in the heart: the cardiac chambers enlarge and the heart muscle becomes thicker than normal, which is usually known as "athlete's heart". It has been hypothesized that prolonged aerobic exercise is more prone to lead to these changes; therefore, groups of ultra-endurance athletes (including cyclists, Ironman triathlon athletes and ultra-marathon runners) have often been assessed to study this relationship. These unique athletes compete in events that can last up to 30 hours; they usually train between 20-40 hours per week and expend over 70,000 KJ/ week. In addition, it should be noted that the number of individuals participating in these events is continually increasing as evidenced by the number of new races established each year.

The results of the studies are somewhat conflicting. Some authors reach the conclusion that ultra-endurance exercise elevates oxidative stress, leading to the development of acute cardiac dysfunction as evidenced by electrocardiography abnormalities, myocardial injury or atherosclerosis, consequently increasing the risk of cardiovascular diseases and mortality (Knez, Coombes and Jenkins, 2006; Laslett, Eisenbud and Lind, 1996). La Gerche *et al.* (2012) found that endurance training leads to cardiac dysfunction that predominantly

affects the right ventricular, which correlates with increases in biomarkers of myocardial injury and it is more prevalent in athletes with a longer history of competitive sport. In contrast, other studies do not find measurable persistent abnormalities of cardiac function in ultra-endurance elite athletes, suggesting that the response to oxidative stress might be mitigated as a result of exercise-induced adaptations, such as increased antioxidant defense and less reactive oxygen species production (La Gerche *et al.*, 2004).

In a comprehensive study assessing world-class endurance athletes (Pelliccia *et al.*, 2010), no cardiovascular events occurred and uninterrupted training/competition over long periods of time (for more than eight years on average) was not associated with deterioration in left ventricular function, significant changes in left ventricular morphology or onset of symptoms of cardiomyopathies.

The debate on the consequences of heart remodeling in elite athletes and the safety of long-term and intense sports participation is fueled by news media reports of sudden cardiac deaths. The most shocking case in Portugal was the death of the professional football player Miklós Fehér at age 24, during a match (2004). The cause of death was cardiac arrhythmia, brought on by hypertrophic cardiomyopathy, which is known as a leading cause for cardiac arrests in young athletes and it usually asymptomatic.

Along with the premature deaths, the high frequency of injuries has brought some sports under increased scrutiny, especially those with a high risk of bodily collision and high physical contact. For instance, chronic traumatic encephalopathy is a progressive degenerative disease, most commonly found in elite athletes participating in American football, boxing, ice hockey and rugby, with a history of repetitive brain injuries, including symptomatic concussions (Koning *et al.*, 2014; McKee *et al.*, 2009; Zwiers *et al.*, 2012). This disease leads to early onset dementia and it is associated with reduced life expectancy.

A number of studies have thus attempted to study the risk-benefit ratio of intensive exercise by assessing mortality in elite athletes. The scientific literature, which is reviewed in Chapter 2, provides a major evidence of lower mortality in elite athletes, as well as a higher life expectancy.

Following the brief introduction and the literature review, Chapter 3 introduces the main methods used to assess mortality of a population, with particular evidence given to its comparison to a standard population.

The main findings in the literature on elite athletes' mortality vary according to nationality and sport practiced. In addition, the methods employed, the period of enrollment

in sports or the follow-up time provide large variations in the results. Consequently, estimates from these studies are not easily transposable to other elite populations.

An exhaustive research on this topic was performed and, to date, it was not found any study on the mortality/longevity of Portuguese athletes, whether among professional or amateurs, male or female. Given the interest in this population, the next step of this work involved the collection and creation of the data set, which revealed to be one of the most time-consuming tasks. It has implied contacting and visiting the Portuguese Federations of several sports, the Portuguese Institute of Sports and Youth (Instituto Português do Desporto e Juventude) and the office of the insurance company Fidelidade (which works with sports and health insurance of high performance athletes). At the end, internet has showed to be the best source of data. The only successful group of Portuguese elite athletes for whom it was possible to create a data set was the football players, in particular, those who have already represented the National Team. In order to have a broader study, data on Spanish football team players was also collected, resulting in an Iberian analysis.

The process of data collection, the statistical analysis and the results obtained are presented in Chapter 4, the main contribution of this paper. Regarding the software employed in this work, Excel was used for data set building and making simple analyses; R was the chosen tool to compute mortality measures and to develop regression models.

Finally, Chapter 5 includes the relevant conclusions, limitations of the study and topics for future research.

Chapter 2 – Literature Review

A majority of studies assessing elite athletes' mortality and longevity shows that elite athletes survive longer than the general population, with these differences being more pronounced for endurance and mixed-sport athletes.

In two different studies of cyclists who have participated in the Tour de France, it was reported a substantially and significantly lower mortality in cyclists, compared to the general male population (Marijon *et al.*, 2013; Sanchis-Gomar *et al.,* 2011). These professional cyclists constitute one population of particular interest, since Tour de France is one of the most demanding and difficult sports event in the world, during which cyclists cover around 3500km in three weeks.

Sanchis-Gomar *et al*. (2011) consider the participants in the Tour de France between the years 1930 and 1964, excluding cyclists for whom they do not have proof of date of birth or death, who did not complete all stages and who were born in countries that have contributed with less than 100 participants during this period. The final sample consists of 834 cyclists, from France (n=465), Italy (n=196) and Belgium (n=173). Portuguese cyclists are not included, since they only represented 0.24% of the total number of participants. The authors compute the "percentage of survivors" for each age, given by the number of cyclists born in a given year who were alive on 31 December 2007, divided by the number of cyclists born in that given year. This survival rates are compared with those of the pooled general population of France, Italy and Belgium, for the appropriate birth cohorts (men born between 1892 and 1942, the years in which the cyclists studied were born). A polynomial regression curve of second order (Ribeiro, 2014; Wooldridge, 2012), in the age–survival (%) axis, is adjusted for each population and a non-parametric Mann-Whitney U test (Mann and Whitney, 1947) is applied for comparing the mean of the percent survival. The curve of the cyclists lies above the curve of the general population for all ages and by comparing the areas under the curves, the authors reach the conclusion that longevity of the cyclists is significantly higher ($p<0.05$). The estimated average of survival between 65 and 115 years is 39.1% in cyclists, while for the general population it is 21.5%. The authors also compare the age at which 50% of the population dies: 73.5 years for the general population vs. 81.5 years in the Tour de France participants.

In the study including only the French cyclists participating at least once in Tour de France from 1947 to 2012 (Marijon *et al.*, 2013), the reduced mortality was confirmed with the calculation of standardized mortality ratios and their 95% confidence intervals, by age-

categories, calendar periods and specific causes of death, besides the overall ratio. A measure of longevity was also used, namely, the additional life span of cyclists who participated in the Tour between 1947 and 1951, which is estimated by 6.3 years compared to the reference population.

Lin, Gajewski, and Poznańska (2016) applied a parametric frailty survival model to a group of Polish athletes who have participated in the Olympic Games from 1924 to 2010. The study was restricted to the athletes born between 1890 and 1959, after concerns about medical improvements and the statistical power for parametric survival analysis. The authors fitted a ϒ-Gompertz hazard function to account for possible unobserved heterogeneity (ϒ; variance), which can arise from different region of birth, energy expenditure, nutrition and so on. The hazard function is given by $\mu(x) = a.e^{bx}$, therefore, the parameter b measures the rate of ageing and a represents the magnitude of the hazard. The athletes were preassigned to two birth cohorts, 1890-1919 (cohort I) and 1920-1959 (cohort II), in order to account for socioeconomic changes and medical advancements. Results from cohort I suggest that Polish elite athletes exhibit lower risk of mortality and a slower rate of ageing (b_{oly}=0.08616) than the general population from the same birth cohort (b_{hmd}=0.09762). Regarding cohort II, mortality risk is also lower for athletes than for the general population, however, the estimated rate of ageing is similar (b_{oly}=0.08467 and b_{hmd}=0.08327). This last result may be attributed to mortality improvements in Poland from year 1920 onwards. Actually, athletes benefited from a 50% reduction in mortality from cohort I to cohort II and the estimated overall mortality risk of the Polish general population is 29% lower in Cohort II than in I.

Sarna *et al.* (1993) estimated that Finnish long-distance runners and cross-country skiers, competing internationally between 1920 and 1965, live 5.7 years longer than age and area of residence-matched reference male cohorts in Finland.

Regarding team sports athletes, for example, baseball players (Abel and Kruger, 2005; Kalist and Peng, 2007) and National Football League (NFL) players (Koning *et al.*, 2014) show lower mortality rates than general population.

There are many possible explanations for this apparent survival advantage of elite athletes. High physical fitness levels, achieved by daily vigorous exercise, are one of the crucial beneficial factors. Such excellence in sport is attained only by the healthiest and the fittest individuals, which may be partially explained by genetic predisposing factors; therefore, professional athletes are usually regarded as a select group. Moreover, elite athletes have a better access to quality health care, due to their medical team support and higher incomes in general. Commonly, they are no-smokers, follow a healthy diet and consume less

alcohol than the general population. Finally, elite athletes, especially endurance ones, tend to maintain these healthy lifestyle habits and remain active after retirement.

However, a few studies do not find a survival benefit of elite athletes. For example, Italian soccer players active in the three top leagues, between 1960 and 1996, do not show a mortality difference from the Italian population (Belli and Vanacore, 2005). Likewise, New Zealand rugby players had the same life expectancy as the general population (Beaglehole and Stewart, 1983).

Furthermore, there is a report by Pärssinen *et al.* (2000) observing that 12.9% of Finnish powerlifters died prematurely (mean age of death=43 years) compared to 3.1% of the general population during a 12-year follow-up period. The use of anabolic steroids to enhance performance and the higher prevalence of obesity and diabetes later in life are reasons proposed for the higher mortality of powerlifter athletes.

In some cases, an excess mortality by specific causes of death is observed for elite athletes, in comparison with standard population.

Two distinct studies conclude that Italian soccer players have considerably high death rates for diseases of the nervous system, mainly from amyotrophic lateral sclerosis (ALS). Belli and Vanacore (2005) reached a standardised proportionate mortality ratio for ALS of 11.58, when analysing Italian soccer players active in the period 1960-1996. Taioli (2007) studied a cohort of soccer players who were enrolled in the Italian A and B professional leagues for at least one season, between 1975 and 2003, recording a standardised mortality ratio for ALS of 18.18, without significant variation across calendar year.

Although the overall mortality was significantly reduced in the cohort of 3439 NFL players, with at least 5 pension-credited playing seasons from 1959 to 1988 (SMR=0.53), neurodegenerative mortality was estimated to be three times greater than that of the general US population, possibly related to the higher chronic traumatic encephalopathy (Lehman *et al.*, 2012).

In contrast to the studies presented before, where elite athletes are compared to the general population, in one article by Zwiers *et al.* (2012), the comparison is made among the Olympic athletes practicing sports with different levels of physical intensity and contact. The study assesses the mortality risk of 9889 athletes who participated in the Olympic Games between 1896 and 1936 in 43 different disciplines, which are classified in categories of: static intensity, dynamic intensity, cardiovascular intensity, physical contact and bodily collision. The authors calculate hazard ratios for all-cause mortality by using a left truncated Cox Proportional Hazard model (Cox, 1972). The results show that Olympic athletes engaging in

disciplines with increasing cardiovascular intensity are not associated with a significantly higher mortality risk. A separate analysis of the static and dynamic components shows similar non-significant results. These conclusions do not change under a multivariate analysis. The study points a higher mortality for those practicing sports with a high risk of bodily collision and high physical contact (hazard ratios of 1.11 and 1.16, respectively). A note for the fact that bodily collision becomes non-significant in a multivariate analysis, as a consequence of its close relation with physical contact. Identical analysis is developed for subgroups – men only, deaths after age 50, born before/after 1900 – and the results are similar to the mentioned above.

Other works show that mortality results vary even for athletes practicing the same sport. For instance, in the study including NFL players from two different seasons (Koning *et al.*, 2014), besides the analysis of overall mortality, the players are divided in subgroups, by race, position played (line, skill and other) and number of games during their career. A Cox Proportional Hazard Model is developed to examine if the observable risk factors mentioned above influence mortality within the population of NFL players. There is evidence that line players have higher mortality than other players, which is expected since they are more susceptible to some kind of diseases (e.g.: cardiovascular diseases due to their higher body mass index (BMI)). In the 1970 cohort, white players exhibit a 33% lower hazard rate than non-white players, but this difference is no longer valid for the 1994 cohort. An interesting finding is that players who play more than two seasons worth of games face higher mortality rates than other players, registering a 347% higher hazard rate. In another study using a different cohort of NFL players, Baron *et al.* (2012) evaluated the association of position category and BMI with cardiovascular disease mortality. The BMI was treated as a categorical variable, with three levels: normal (18.5 to <25 kg/m^2), overweight (≥25 to 30 kg/m^2) and obese (≥30 kg/m2). Among other results, the authors found that CVD mortality was increased for players with BMI≥30kg/m^2 in comparison to normal BMI (HR: 2.02; 95% CI: 1.06 – 3.85) and for defensive linemen compared to offensive linemen (HR: 2.07; 95% CI: 1.24 – 3.46).

Chapter 3 – Methods to quantify and compare mortality

This chapter introduces the methodologies used to quantify and compare the mortality experience of different populations, and to monitor the progress over time of the populations' mortality. In this analysis, there is a special focus on comparing the mortality of the population under study (specific cohort of elite athletes) with a standard population (reference/general population).

3.1 Measures of comparative mortality

One of the possible approaches involves the computation of summary (single figure) mortality indices. The general notation and definitions will be presented, having as main references the Core Reading - Subject CT5 in IFOA (2011), and Breslow and Day (1987).

In the context of comparing the mortality results of different populations, a problem arises if they have different structures with respect to background characteristics. One example is comparing mortality figures of populations (for example, Portuguese cyclists and Portuguese football players) with different age distributions. In this case, rates and ratios must be adjusted to ensure the comparability between the heterogeneous populations, a process known as **standardisation**, which has been used in actuarial applications since the mid-18th century (Keiding, 1987). Besides the example of age, mortality rates are commonly standardised by sex, race and calendar period. Other factors such as occupation, nutrition, housing, education and genetics, also contribute to differences in mortality (distorting variables); nevertheless, extensive data may be required so these adjustments are less frequently applied. Each population is said to be decomposed in groups (strata), having certain characteristics in common. Throughout this study, mortality rates are standardised by sex, age and calendar period. For example, one possible stratum could be: men, aged 30-35, during calendar period 1950-1955.

Mortality rates can be calculated either for total deaths or for separate causes of interest. However, only overall mortality rates are computed here, since it was not possible to obtain the cause of death for most athletes.

3.1.1 General notation

Considering that the population being studied is divided in M classes (groups, strata), the following notation will be used for the cohort:

- E_j: central exposed to risk in class j $(j = 1, \dots, M)$
- d_j: number of deaths in class j $(j = 1, \dots, M)$
- m_j: central rate of mortality in class j $(j = 1, \dots, M)$

The notation is modified by the addition of the superscript "s" when it refers to the standard population, instead of the population under study. For example, ${}^{s}E_j$ is the central exposed to risk in class j in the standard population.

The central rate of mortality is preferentially used in population studies, in opposition to the initial rate of mortality (probability of death), q_x. This last one is obtained dividing the number of deaths, d_x, by the number of individuals alive at age x, l_x. Intrinsically, it is assumed that l_x individuals are alive between ages x and $x + 1$, which is an inconvenient, since people who die during that year of age will not be exposed to risk during the whole year. As an alternative measure, m_x is computed dividing d_x by the expected number of individuals living between ages x and $x + 1$ (exposure-to-risk), given by $\int_0^1 l_{x+t}\, dt$. So, while q_x is the probability of an individual now aged x dying within the next year, m_x is the probability of a life aged anywhere between x and $x + 1$ dying before attaining age $x + 1$.

3.1.2 Computation of central exposed to risk

The central exposed to risk for an individual in the j-th group is the period of time during which the individual is followed-up in that group, from his/her entry until his/her exit. E_j is obtained by summing up the contributions of all individuals in the same stratum j. The **total exposed to risk**, also known as **population at risk** or **exposure-to-risk**, is determined by adding up the values of the central exposed to risk of all categories, from $j = 1$ to $j = M$. The mortality rates are often expressed in terms of annual rates (i.e., per year) and in this case the exposed to risk is called "person-years" of observation.

As a first approach, exposure-to-risk will be determined considering only standardisation by age. In this case, $E_{x,t}$ is used to denote the central exposed to risk in the population being studied between ages x and $x + t$.

In cohort studies during a long period of time there are inevitably withdrawals of individuals (due to death, inability to trace…) and often new individuals are added to the cohort.

Defining:

- Date A = max (date of reaching age x, start of the investigation, date of entry)
- Date B = min (date of reaching age $x + t$, end of investigation, date of exit)

$E_{x,t}$ for an individual is given by Date B – Date A

The evaluation of central exposed to risk becomes more difficult when stratification is performed with respect to other variables besides age. As already mentioned, the standardisation of individual follow-up time in this study is performed by age, calendar period and sex. First, for each individual, it is determined the amount of observation time contributed to each category, defined by a combination of the three variables. Subsequently, the observed times of all cohort members are summed up to obtain the population at risk in that same category.

For the population of football players, which is composed only of men, the categories are defined by a given age-band and a certain calendar period. The calendar scale as well as the age scale are often divided in one, five or ten-year intervals, in order to make the published national death rates directly applicable in the computation of the expected number of deaths.

As a simple illustration, consider a player, who was born on 15 February 1980, enters the study on 5 April 2002 and leaves the study on 14 June 2005. Therefore, he starts to be followed with 22.13 years (point A) and his age at exit will be 25.33 years (point B). Considering age-class and calendar period of one year, he contributes with observation times to seven different categories, as shown in Figure 3.1.

The exposed to risk of each category equals the corresponding width of the lattice at the bottom. Since the two variables in the axes have the same scale, only four different values of exposed to risk need to be calculated, namely, the first and the last widths of the lattices (in the example, 1 and 7, respectively); the value of the lattices with even numbers and the value of the lattices with odd numbers.

Define $WIDTH$ as the width of each variable in the axis and consider $aux1$, $aux2$, $aux3$ and $aux4$ as illustrated in Figure 3.1.

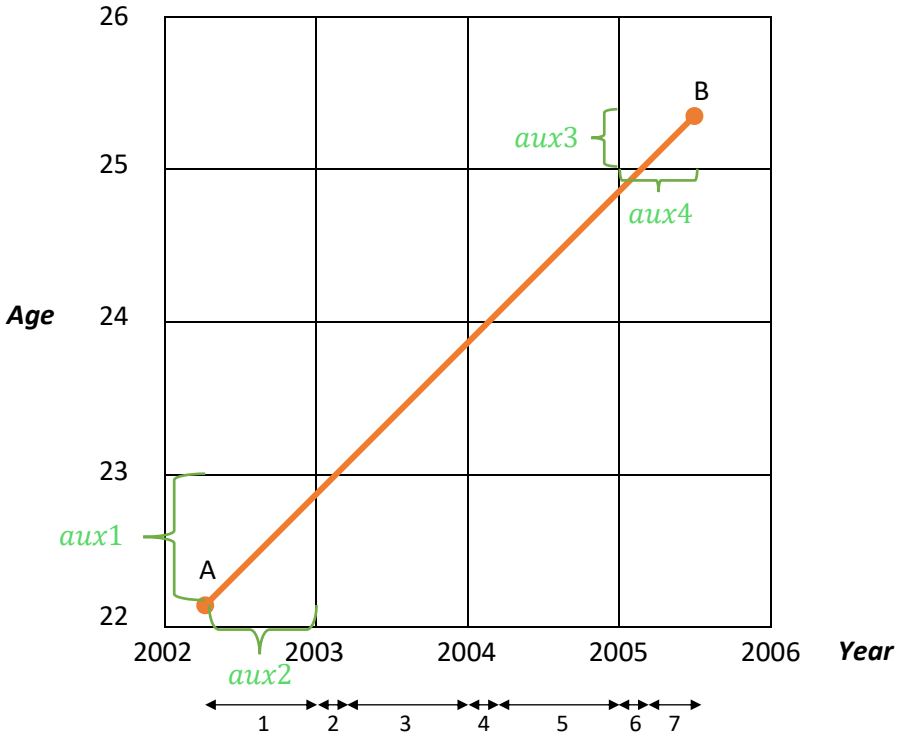

Figure 3.1 – Lexis diagram divided into 1x1 cells (one year of age by one year of time) to illustrate the follow-up of a hypothetic individual and the computation of his exposure to risk.

The property of the sum of neighbor widths being equal to the scale of the original variables ($WIDTH$), unless one of them is the first or the last lattice, allows determining the population at risk:

$$width1 = min\{aux1, aux2\}$$
$$width2 = |aux1 - aux2| (= width4 = width6)$$
$$width3 = WIDTH - width2 (= width5)$$
$$width7 = min\{aux3, aux4\}$$

The individual contribution to the exposed to risk by this athlete is summarised in Table 3.1, where values are in days. Notice that the output obtained when using software may be different, since some adjustments are usually performed to consider leap years and assumptions about the date of entry and exit are made, namely, whether they count for the observed time.

Age	**Calendar year**			
	2002	**2003**	**2004**	**2005**
22	271	45		
23		320	45	
24			320	45
25				120

Table 3.1 – Central exposed to risk (in days) by age and calendar year for the hypothetic individual

The computation of exposed to risk is crucial for evaluating the following mortality measures.

3.1.3 Crude Mortality Rate (CMR)

The crude (non-standardised) mortality rate for a particular population is the total number of deaths observed during the period divided by the total exposed to risk for the same period.

$$Crude\ mortality\ rate = \frac{\sum_{j=1}^{M} E_j\, m_j}{\sum_{j=1}^{M} E_j} \quad (1)$$

This rate can be calculated just for a certain category, for example, as the ratio of total number of deaths in one age-class to the total exposed to risk in the same age-class.

Comparing crude mortality rates of different populations might give a misleading result, since the measure does not take into account differences in their demographic structures. In particular, the crude mortality rate disregards the age structure of the population. If one population is, on average, younger than the other, then, even if the age-specific rates were the same in both populations, more deaths would occur in the older population than in the younger, considering exactly the same period of observation. Actually, given higher crude mortality rates in a population X at each age-class than in a population Y, it is possible to obtain a lower overall crude mortality for population X, as illustrated in the example below.

	Population X			Population Y		
Age (j)	Exposed to risk	Deaths	CMR_j	Exposed to risk	Deaths	CMR_j
20	75 000	225	0.003	10 000	20	0.002
40	15 000	75	0.005	15 000	60	0.004
60	10 000	100	0.010	75 000	525	0.007
Total	100 000	400		100 000	605	
	$CMR_X = 0.004$			$CMR_Y = 0.00605$		

Table 3.2 – Example of computation of CMR to illustrate that this measure can be misleading if used to compare the two populations. *Adapted from: IFOA (2011), Core Reading: Subject CT5, Chapter 15.*

A valid comparison is obtained when the mortality rate is recomputed by assuming the same age structure in the two populations, which is one form of standardisation, as already mentioned.

There are two types of standardisation, direct and indirect, both requiring assumption of a standard or reference population.

3.1.4 Directly Standardised Mortality Rate (DSMR)

The directly standardised mortality rate is obtained by applying the stratum-specific cohort mortality rates to the standard population distribution. More formally:

$$DSMR = \frac{\sum_{j=1}^{M} {}^{s}E_j \, m_j}{\sum_{j=1}^{M} {}^{s}E_j} \tag{2}$$

This measure can be regarded as a weighted average of the stratum-specific cohort mortality rates, with the weights being the stratum-specific proportions in the standard population, ${}^{s}w_j = \frac{{}^{s}E_j}{\sum_{j=1}^{M} {}^{s}E_j}$: (3)

$$DSMR = \sum_{j=1}^{M} {}^{s}w_j m_j \tag{4}$$

If the standardisation is only by age, the directly standardised mortality rate is the number of deaths that would have occurred in the standard population if it had the age-specific mortality of the cohort, divided by the total central exposed to risk of the standard population. Provided that the same reference population is used in the standardisation, computation of directly standardised rates is expected to provide a meaningful comparison between the mortality experience of different cohorts, by eliminating the effect of different age structures. However, the standard population affects this measure, so it should be chosen carefully.

3.1.5 Indirectly Standardised Mortality Rate (ISMR)

The indirectly standardised mortality rate is defined as the crude mortality rate for the standard population multiplied by the ratio of actual to expected deaths in the cohort, as follows:

$$ISMR = \frac{\sum_{j=1}^{M} {}^{s}E_j \, {}^{s}m_j}{\sum_{j=1}^{M} {}^{s}E_j} \times \frac{\sum_{j=1}^{M} E_j \, m_j}{\sum_{j=1}^{M} E_j \, {}^{s}m_j} \tag{5}$$

The rate can also be decomposed as:

$ISMR = F$ x CMR for population under study ,

where $F = \frac{\frac{\sum_{j=1}^{M} {}^{s}E_j \, {}^{s}m_j}{\sum_{j=1}^{M} {}^{s}E_j}}{\frac{\sum_{j=1}^{M} E_j \, {}^{s}m_j}{\sum_{j=1}^{M} E_j}} = \frac{Crude\ mortality\ rate\ for\ standard\ population}{Crude\ mortality\ rate\ for\ cohort,\ \ using\ standard\ mortality}$ (6)

is the Area Comparability Factor. A value of F greater than 1 indicates that the structure of the population being studied is more heavily weighted towards individuals who experience lighter mortality than the standard population.

Usually, the indirectly standardised mortality rate gives a good approximation to the directly standardised mortality rate and it is often more easily calculated, since it is not necessary to know the stratum-specific mortality rates of the cohort (only the total number of deaths).

It is possible to take important conclusions from the last single figure indices:

- If the DSMR, the ISMR and the crude mortality rate for the standard population are greater than the crude mortality rate for the studied population, then, the reason for the lower mortality rate of the cohort is its population distribution (by the variables being used in the standardisation);
- If the crude rate for the standard population is greater than both the DSMR and ISMR, the crude rate for the studied population is lower, even allowing for the population distribution.

3.1.6 Standardised Mortality Ratio (SMR)

The standardised mortality ratio has been one of the most used summary mortality measures. The SMR compares the observed number of deaths in the population being studied with the expected number of deaths obtained by applying the stratum-specific mortality rates of the standard population to the corresponding population at risk in the cohort.

It is formally defined as:

$$SMR = \frac{\sum_{j=1}^{M} E_j m_j}{\sum_{j=1}^{M} E_j \ {}^{s}m_j} = \frac{\sum_{j=1}^{M} d_j}{\sum_{j=1}^{M} E_j \ {}^{s}m_j} = \frac{actual\ deaths\ in\ the\ cohort}{expected\ deaths\ in\ the\ cohort} \qquad (7)$$

Notice that the indirectly standardised mortality rate is obtained multiplying the crude mortality rate of the standard population by the SMR.

One advantage of the SMR is that stratum-specific numbers of deaths (or stratum-specific mortality rates) in the cohort are not required for its calculation, only the total number of deaths. This allows application of the SMR to published data which omits details on the number of deaths by subgroup but gives information about the population at risk.

A value of the SMR lower than 1 indicates that the study population exhibits lower mortality than the standard population, and vice-versa.

Besides estimating the SMR, one question of interest is its statistical significance. The hypothesis test and the determination of confidence intervals are explained in the Appendix.

This summary statistic is widely used in studies on mortality and longevity of elite athletes, engaging in different types of sports:

- An overall SMR of 0.59 shows a substantially and significantly lower mortality in French participants in the Tour de France compared with the general French male population

(Marijon *et al.*, 2013). Cyclists are also grouped in the intervals 1947-70, 1971-90 and 1991-2010, according to their participation in Tour de France. The reason behind this is to address (indirectly) the possible effect of doping on long-term mortality and to account for mortality trends. For the first two periods, it is observed a 41% and 32% lower mortality in French cyclists, while no deaths are recorded in the last period. It is also taken into account a possible age period interaction, again resulting in SMR lower than 1, without any significant difference over time. Reduction in mortality is also verified for major causes of death, which are neoplasms (SMR: 0.56) and cardiovascular diseases (SMR: 0.67). The exception is mortality associated to external causes (mainly, trauma-related), with no clear difference between cyclists and the general population.

- Taioli (2007) concluded that the SMR of the cohort of professional soccer players enrolled in Italian A and B leagues from 1975 to 2003 is 0.68, based on age and calendar-period stratified mortality from the general male population in Italy. However, a significantly higher than expected number of deaths for ALS and car accidents was observed, giving SMR of 18.18 and 2.23, respectively.

- The mortality experience of Major US league baseball players is found to be lower than that of the reference population in several studies. For example, Kalist and Peng (2007) observe an actual number of deaths 69% lower than the expected (SMR=0.31), for players born between 1945 and 1964; Reynolds and Day (2012) compute a SMR which is higher but still significantly lower than 1 (SMR=0.87) for the 1930-1999 period.

- In another study including the Polish athletes participating in the twentieth century Olympics since 1924, the SMR is 0.5 for males and 0.73 for females, using as standard population the urban Polish males, and females, respectively, also stratifying by age (Gajewski and Poznańska, 2008).

- Danish athletic champions, record-holders and members of national teams from 19 different sports, born in the calendar-period 1880-1910, are divided in three age-classes in a study conducted by Schnohr (1971). The male elite athletes had a significantly lower mortality than the standard population under the age of 50 years (SMR=0.61 in the life period 25-49 years), while the actual deaths were not significantly different from the expected deaths after 50 years old (SMR=1.08 in 50-64 years and SMR=1.02 in 65-80 years).

The standardised mortality ratio is also used to evaluate morbidity rates, being known in this context as standardised incidence ratio (SIR), a summary statistic that assesses the risk associated with a specific disease. The SMR and SIR are particularly applicable when the population under study is so small, or the event of interest is rare, that the resulting stratum-specific rates are not stable.

3.2 Observed and expected survival function

Besides providing single summary measures of mortality, it is useful to compare two (or more) populations based on the estimation of their survival functions.

The survival function is defined as $S(t) = P(T > t) = {}_tp_0$ and represents the probability that an individual at time or age 0 survives at least t years. On the other side, the lifetime distribution function from time or age 0 is defined as $F(t) = 1 - S(t) = P(T \leq t) = {}_tq_0$, and represents the probability that the individual does not survive beyond time or age t.

3.2.1 Kaplan-Meier method – Estimation of observed survival

The Kaplan-Meier estimator of the survival function is one of the most widely used methods for statistical comparison and graphic display of survivorship over time, not requiring a functional form for the survival function (non-parametric).

Individuals in the cohort are followed from their entry into study until they die, withdraw from the investigation while still alive or reach the time of end of the investigation, whichever of these three events occurs first. These last two situations are examples of right censoring, which plays an important role in estimating survival rates.

In the next presentation of the Kaplan-Meier method (Klugman, Panjer and Willmot, 2008) lifetimes will be considered as a function of time t,without mention of a starting age x.

Suppose the population under study is composed of *N* individuals, in the presence of non-informative censoring, and *d* deaths are observed. Then, $N - d$ lives are censored. Let:

- $t_1 < t_2 < \ldots < t_k, k \leq d,$ be the ordered times at which deaths are observed. Define $t_0 = 0$;
- d_j denote the number of deaths at time t_j $(j = 1, \ldots, k)$, with $d_j \geq 1$ ($d = \sum_{s=1}^{k} d_s$);
- r_j, known as the risk set, denote the number of individuals alive and uncensored at t_j^- $(j = 1, \ldots, k)$;
- c_j denote the number of individuals censored in the interval $[t_j, t_{j+1}[$ $(0 \leq j \leq k-1)$.

Therefore, $r_1 = N - c_0$ and $r_j = N - \sum_{s=1}^{j-1} d_s - \sum_{s=0}^{j-1} c_s$, $2 \leq j \leq k$.

$$\Rightarrow r_j = r_{j-1} - d_{j-1} - c_{j-1}, 2 \leq j \leq k.$$

It can be shown that the Kaplan-Meier estimate, $\hat{S}(t)$, is a monotonically non-increasing step function and is obtained by multiplying the survival probabilities, $\frac{number\ of\ survivors\ at\ t_j}{risk\ set\ at\ t_j}$, within each of the intervals up to and including duration t:

$$\hat{S}(t) = \begin{cases} 1, & t < t_1 \\ \prod_{s=1}^{j-1} \frac{r_s - d_s}{r_s}, & t_{j-1} \leq t < t_j \\ \prod_{s=1}^{k} \frac{r_s - d_s}{r_s} \quad or \ 0, & t > t_k \end{cases} \tag{8}$$

3.2.2 Estimation of expected survival

The expected survival function is estimated to provide a comparison between the survival of the population of elite athletes and the standard population. The most common approaches are the exact method, the cohort method and the conditional expected survival. These three methods differ in how long the athlete's counterpart in the standard population is considered to be at risk for the calculation of the expected survival.

The **exact method**, also known as **Ederer I method** (Ederer, Axtell and Cutler, 1961), assumes a complete follow-up for all athletes; consequently, the matched individuals are considered to be at risk indefinitely. There is a technical problem with this method, since it often requires standard population data that is not yet available, namely, for the younger individuals under study.

The **conditional expected survival**, known as **Ederer II method** (Ederer and Heise, 1959), is based on the actual follow-up time, therefore, matched individuals are considered to be at risk only until the corresponding athletes die or are censored.

The **cohort method**, proposed by **Hakulinen** (Hakulinen, 1982), takes into account potential follow-up time, which is the maximum possible time that an individual can be followed-up from the date of entry into study to the last potential time of observation. Explicitly, if the study subject is censored, the matched referent is assumed to be no longer at risk (actual follow-up), but if he dies, the counterpart is considered to remain at risk (maximum potential follow-up).

In the following (Pokhrel, 2007; Therneau and Offord, 1999), brief formulae for the estimation of expected survival by each method is given, applying, for simplicity, the convention that both the begin date and the end of follow-up occurred on an individual's birthday. Again, lifetimes will be considered as a function of time t $(t \geq 0)$.

Let $\boldsymbol{p_{ik}^{s}}$ be the annual conditional expected survival probability of a corresponding person in the standard population similar to the i^{th} athlete, with respect to age and calendar year of entry into study. The expected probabilities for individual i, obtained from the standard life tables, can be summarized as follows (Table 3.3).

Interval	Age	Calendar year	p_{ik}^s
[0,1[	a	y	p_{i1}^s
[1, 2[	a+1	y+1	p_{i2}^s
…	…	…	…

Table 3.3 – Illustration of age and calendar year specific annual survival probabilities.

The expected probability of individual i surviving until the end of interval $[t-1, t[$ is then obtained by the product:

$$S_i^s(t) = \prod_{k=1}^{t} p_{ik}^s \tag{9}$$

Exact method

The cumulative expected survival probability from beginning of study to the end of interval $[t-1, t[$ is estimated by:

$$\tilde{S}(t)^{EI} = \frac{1}{l_1}\sum_{i=1}^{l_1}\left(\prod_{k=1}^{t} p_{ik}^s\right) = \frac{1}{l_1}\sum_{i=1}^{l_1} S_i^s(t)\ , \tag{10}$$

where l_1 is the number of individuals at risk at the start of the first interval (which is equivalent to N, defined in section 3.2.1). Therefore, the estimate by the exact method is an average of the cumulative expected survival probabilities of all individuals who enter into study.

Conditional expected survival

The first step in Ederer II method consists in calculating the annual survival probabilities for each interval $[k-1, k[$:

$$p_{*k}^s = \frac{1}{l_k}\sum_{i=1}^{l_k} p_{ik}^s \qquad (k = 1,2, \dots), \tag{11}$$

where l_k is the number of individuals at risk (alive and not censored) at the start of interval $[k-1, k[$. The next and final step is obtaining the estimate of the survival function at time t:

$$\tilde{S}(t)^{EII} = \prod_{k=1}^{t}\left(\frac{1}{l_k}\sum_{i=1}^{l_k} p_{ik}^s\right) = \prod_{k=1}^{t} p_{*k}^s \tag{12}$$

Cohort method

The cohort method for the estimation of the expected survival function was initially proposed by Hakulinen (1982).

After specifying the potential follow-up times for all individuals, let consider a generic interval $[k-1, k[$. From the group of individuals with potential follow-up greater or equal to $k-1$, define two subgroups: α_k having a potential follow-up greater or equal to k and β_k having a potential follow-up less than k. The latter are, in effect, those who withdraw during the interval. An expected life table can be built considering:

- the expected number of individuals alive and under observation at time $k-1$:

$$l_k^* = \begin{cases} l_1 & ,if\ k = 1 \\ \sum_{i \in \alpha_{k-1}} S_i^s(k-1) & ,if\ k \geq 2 \end{cases} \quad (13)$$

- the expected number of deaths among the α_k group during interval $[k-1, k[$:

$$d_k^* = \begin{cases} \sum_{i \in \alpha_k} [1 - p_{ik}^s] & ,if\ k = 1 \\ \sum_{i \in \alpha_k} S_i^s(k-1) \times [1 - p_{ik}^s] & ,if\ k \geq 2 \end{cases} \quad (14)$$

- the expected number of individuals withdrawing alive during interval $[k-1, k[$:

$$w_k^* = \begin{cases} \sum_{i \in \beta_k} \sqrt{p_{ik}^s} & ,if\ k = 1 \\ \sum_{i \in \beta_k} S_i^s(k-1) \times \sqrt{p_{ik}^s} & ,if\ k \geq 2 \end{cases} \quad (15)$$

- the expected number of deaths among the β_k group, during interval $[k-1, k[$:

$$\sigma_k^* = \begin{cases} \sum_{i \in \beta_k} \left[1 - \sqrt{p_{ik}^s}\right] & ,if\ k = 1 \\ \sum_{i \in \beta_k} S_i^s(k-1) \times \left[1 - \sqrt{p_{ik}^s}\right] & ,if\ k \geq 2 \end{cases} \quad (16)$$

- the total expected number of deaths during interval $[k-1, k[$:

$$D_k^* = d_k^* + \sigma_k^* \quad (17)$$

Then, the expected interval-specific survival probability is estimated using the actuarial (life table) approach:

$$p_*^s(k) = 1 - \frac{D_k^*}{l_k^* - \frac{w_k^*}{2}} \quad (18)$$

Finally, the expected cumulative survival from the beginning of the first interval to the end of interval $[t-1, t[$ by the Hakulinen method, is given by:

$$\tilde{S}(t)^H = \prod_{k=1}^{t} p_*^s(k) \quad (19)$$

3.3 Years of Life Lost/Saved

Most of the studies included in literature review use indirect standardisation of elite athletes' mortality to assess the difference in mortality between two populations or, otherwise, to conclude that there is no statistically significant difference between them. As already mentioned, the clear majority found a greater survival of elite athletes when compared to the general population. While this is a useful approach in mortality comparison and a valuable way to give a background to new research, it may not be straightforward to interpret. For example, a 30% lower mortality is better than a 20% lower mortality, but what does a 10% difference mean in terms of life duration?

A possible tool to provide a time dimension measure for athletes' longevity is determining the number of **years of life lost (YLL)** in case of shorter longevity than the standard population, or **saved**, otherwise. The years lost method, as proposed by Andersen (2013), quantifies the expected number of years of life lost due to a given cause of death before a certain age. It has been primary developed to be applied in studies of cancer patients.

In sports, the overall years lost/saved is obtained as a stand-alone measure of mortality. In addition, it is often determined for each major cause of death, as well as according to the main type of physiological effort, allowing comparisons between groups (Antero-Jacquemin J, 2018).

The determination of YLL (Andersen, 2013) requires the definition of the following measures.

- Life expectancy at time 0: $e_0 = \int_0^\infty {}_tp_0\, dt$ (20)
- Temporary life expectancy, also known as restricted mean life time, between $t = 0$ and $t = x$: ${}_xe_0 = \int_0^x {}_tp_0\, dt$ (21)

The life expectancy at time 0, e_0, corresponds to the area under the survival curve, while ${}_xe_0$ is the area under the curve until the given threshold $t = x$.

Noticing that the equation ${}_tp_0 + {}_tq_0 = 1$ holds, and integrating it from $t = 0$ to $t = x$, another balance equation is obtained:

$$ {}_xe_0 + \int_0^x {}_tq_0\, dt = x\,, \tag{22}$$

where $\int_0^x {}_tq_0\, dt = YLL(0, x)$ is the expected *number of years of life lost before time* x.

Rearranging equation (22), $YLL(0,x)$ is obtained by subtracting temporary life expectancy from x:

$$YLL(0,x) = x - {}_{x}e_0 \tag{23}$$

Graphically, it corresponds to the area above the survival curve, $y = S(t)$, and below the horizontal line at 1, $y = 1$, from $t = 0$ to $t = x$. Equivalently, this is the area under the lifetime distribution function $F(t)$, until $t = x$.

Finally, the years of life lost method can be used to compare life expectancies between two populations. Temporary life expectancy can be expressed as a function of the total number of years and the number of years lost. For example, for country c_1:

$${}^{c_1}_{x}e_0 = x - \int_0^x {}^{c_1}_{t}q_0 \, dt \,, \tag{24}$$

and then the difference between the life expectancies of two populations can be obtained by looking at their years lost as:

$$\begin{aligned} {}^{c_1}_{x}e_0 - {}^{c_2}_{x}e_0 &= \int_0^x {}^{c_2}_{t}q_0 \, dt - \int_0^x {}^{c_1}_{t}q_0 \, dt \\ \Leftrightarrow {}^{c_1}_{x}e_0 - {}^{c_2}_{x}e_0 &= YLL_{c_2}(0,x) - YLL_{c_1}(0,x) \end{aligned} \tag{25}$$

If ${}^{c_1}_{x}e_0 > {}^{c_2}_{x}e_0$, the total number of years lost before x is larger in population c_2 than in c_1. Under the context of this work, denoting c_1 as the group under study and c_2 as the standard population, if the difference in (25) is positive it represents the survival gain, in terms of years saved, of the group of athletes in comparison to the standard population. Otherwise, a negative result in (25) estimates the number of years lost in the group of athletes in relation to the standard population.

The same methodology can be applied when estimating the years saved/lost from a certain cause of death, following the competing risk model (Andersen, 2013), through the replacement of the overall probabilities of dying by the cumulative incidence functions for a specific cause.

Notice that all the quantities presented can be defined conditionally on survival until time $t = x$. For instance, the temporary life expectancy between times x and $x + n$ is: ${}_{n}e_x = \int_0^n {}_{t}p_x \, dt$. Furthermore, time can be interpreted as age. More details can be found in Andersen (2013).

3.4 Cox Proportional Hazard Models

In addition to comparing the mortality of elite athletes with that of a standard population, it is also interesting to analyse if there are mortality differences inside the group of athletes, resulting from having different characteristics. For example, it can be investigated if mortality of a team player (football, baseball, etc.) is influenced by his/her position on the field.

Cox Proportion Hazard Model (Cox, 1972) is applicable in this context, besides being one of the most widely used tools of survival analysis. The quantity that plays a central role in this model is the **hazard rate**, also known as force of mortality, and defined as:

$$\lambda(t) = \lim_{h \to 0} \frac{1}{h} P(T \leq t + h \mid T > t) \ , \tag{26}$$

where T is the random variable representing the future lifetime at time 0. The hazard rate is an *instantaneous* measure of mortality at time t and fully describes the lifetime distribution (as the survival distribution does). If the time scale is age, the hazard rate is usually represented as $\lambda(x)$ and T is the future lifetime at birth.

In the Cox Proportional Hazard Model, the hazard rate takes the form:

$$\lambda(t, \boldsymbol{z}) = \lambda_0(t) e^{\boldsymbol{\beta} \boldsymbol{z}^T} \ , \tag{27}$$

where $\boldsymbol{z}$ is a vector of covariates, which are the different factors used to split the population under study into homogeneous subgroups; $\boldsymbol{\beta}$ is a vector of regression parameters and $\lambda_0(t)$ is the baseline hazard (all $\boldsymbol{z_i} = 0$), a function of time t and independent of the covariates.

This is a *semi-parametric* model since the baseline hazard is unspecified, that is, no assumptions are made about the shape of $\lambda_0(t)$ before analysing the data.

Noticing that the hazards of different individuals with covariate vectors $\boldsymbol{z_1}$ and $\boldsymbol{z_2}$ are in the same proportion at all times:

$$\frac{\lambda(t, \boldsymbol{z_1})}{\lambda(t, \boldsymbol{z_2})} = \frac{e^{\boldsymbol{\beta} \boldsymbol{z_1}^T}}{e^{\boldsymbol{\beta} \boldsymbol{z_2}^T}} = constant \ , \tag{28}$$

Cox regression belongs to the category of *proportional hazard models*.

Since the aim of the analysis is to compare mortality across different groups, $\lambda_0(t)$ can be "ignored". Then, the vector $\boldsymbol{\beta}$ is estimated from the data, through the maximisation of the partial likelihood function and assuming a method (e.g. Breslow's approximation) to handle deaths that occur at the same time. For more details, cf. IFOA (Subject CT4, 2011).

The Cox Proportional Hazard Model is fitted in software R with the *coxph* function, belonging to the package *survival*.

In the literature, there are several works that have used the Cox Proportional Hazard technique to analyse the effect of specific variables in mortality of athletes, as already mentioned in Chapter 2. Here, it should be emphasised that most of them use the age attained by the athlete at entry into study as the relevant time scale, allowing for censored observations (Zwiers *et al.*, 2012; Baron *et al.*, 2012; Koning *et al.*, 2014). Alternatively, follow-up time can be chosen, though being an approach primarily used in epidemiological studies.

The covariates used vary from study to study, depending on the characteristics of the sport, the data availability and the main objective of the research. While Koning *et al.* (2014) focused on overall mortality of NFL players, examining whether observable factors as number of games played, position played and race, influence the individual risk of mortality, Baron *et al.* (2012) studied the association of NFL players position category and BMI with cardiovascular disease mortality. Targeting a broader group of elite athletes, those who participated in the Olympic Games between 1896 and 1936, Zwiers *et al.* (2012) determined hazard ratios for all-cause mortality dependent on different levels of exercise intensity, risk of bodily collision and levels of physical contact.

Besides mortality, Cox Proportional Hazard Models were also used to assess disability relative risks. One example is the study based on a cohort of male Finnish elite athletes (Sarna et *al.*, 1997) evaluating the association between the type of sport – endurance athletes, team games and power sports – with specific disabilities.

The models are usually adjusted for other variables, as race, era of play, time since last game played and calendar year of follow-up (by decades) in Baron *et al.* (2012); sex, year of birth and nationality in Zwiers *et al.* (2012), and marital status and social class in Sarna *et al.* (1997).

Chapter 4 – Applications

The methodologies presented in Chapter 3 will now be applied to populations of elite athletes, to evaluate whether they live longer than the corresponding general population.

It was possible to collect data from two populations of professional football players, who have represented at least once their National Team, namely, the players of the **Portuguese Football Team** and the players of the **Spanish Football Team**.

The overall mortality of players was compared with that of the general population of their respective countries, using the Human Mortality Database (http://www.mortality.org/).

For all data in this collection and throughout the study, age and time are arranged in 1, 5, and 10-year intervals. In the computations, available death rates, exposure-to-risk and life tables are used in the six configurations available in the Human Mortality Database (HMD): 1x1, 1x5, 1x10, 5x1, 5x5, and 5x10, with the first number always referring to the age interval and the second number to the time interval. For example, 1x5 denotes a configuration with single years of age and 5-year time intervals. Furthermore, the intervals are inclusive, both for age and time, in the sense that the age-group 20-24 extends from exact age 20 up to, but not including, exact age 25, as well as the time period designated by 1970-1974 begins at 1 January 1970 and ends at 31 December 1974. Following the convention in the HMD, the first year of life (age 0) is always separated from the rest of its age group (ages 1-4), and the last age category is for ages 110 and above.

In HMD, data is available in periods – **period data**, i.e., by year of occurrence – and in cohorts – **cohort data**, i.e., by year of birth. The statistics are typically collected, published and tabulated in period life tables; hence, this format is preferentially used.

Moreover, in the standardisation process, the central mortality rates (m_j in this study notation) are widely used, which are referred as death rates in HMD. For period life tables, the values of m_j below age 80 are by definition equal to the observed population death rates. At older ages, the number of deaths and the exposure-to-risk eventually become quite small, leading to considerable random variation in observed death rates. In order to obtain an improved representation of the underlying mortality, death rates for ages greater or equal than 80 are smoothed by fitting a logistic function, before being converted to probabilities of death in HMD. For cohort data, this adjustment is not performed.

Regarding statistical analysis, p-values lower than 0.05 were considered to indicate statistical significance and the 95% confidence intervals were calculated using the exact method (Liddell, 1984). All data was analysed using R software (version 3.4.4).

4.1 Mortality of Portuguese Football Players

4.1.1 Data collection and statistical analysis

Data on Portuguese football players who have represented the national team, for the 1921-2015 period, was collected from the official website of the Portuguese Football Federation (http://www.fpf.pt), from a very complete Portuguese website with worldwide statistics of football (http://www.zerozero.pt/) and complemented with other sources (https://eu-football.info/, http://www.national-football-teams.com/). The most difficult information to obtain was the date of death, which sometimes was found by a deep search in the football team's websites, sports news and memorials.

A total of 589 Portuguese football players have represented at least once the national team in either World Cup, European Championships or even friendly games. From this group, 59 football players were excluded owing to unknown date of birth, date of death, or both. Among the remaining 530 footballers, 133 were known to have died by 31 December 2015.

The **follow-up** for each player was defined by the difference between the date of endpoint (31 December 2015 if alive; otherwise, the date of death) and the date of his first match representing the Portuguese football team. The date of the end of the study was the only censoring point. Whenever the year of death was the only information, it was assumed that the player died at the middle of that year. The age of death ranged from 23 to 99 years old, with a mean of 67.98 ($\pm$ 15.63).

Information about the number of games played by the national team and the total number of games in their careers was collected. Players were also placed into one of four positional categories: goalkeeper, defender, midfielder and forward.

Table 4.1 lists summary statistics for the players followed during the 1921-2015 period, which corresponds to years of birth between 1894 and 1997.

The overall mortality of players was compared with that of the Portuguese male population, using the Human Mortality Database.

Notice that period life tables for Portugal are available from 1940 until 2015 and the national team's debut was in 1921, then, cohort life tables were used for the remaining period 1921-1939.

Total number of players	530
Alive at 31 December 2015	397 (75%)
Dead at 31 December 2015	133 (25%)
Age at the first representation (mean±SD)	23.86 (± 3.10)
Age at the end of the study, for the players still alive	52.47 (± 18.25)
Age at death (mean±SD)	67.98 (± 15.63)
Number of games played by the national team (mean±SD)	14.89 (± 20.82)
Number of games played in the entire football career (mean±SD)	309.10 (± 151.87)
Goalkeepers	47
Defenders	163
Midfielders	169
Forwards	151

Table 4.1 - Characteristics of Portuguese Football Players (1921-2015 period).
Sources: FPF; *Zerozero.pt; national-football-teams and eu-football.info*

4.1.2 Results

As a first approach, overall mortality of the Portuguese football players was compared with the Portuguese male population through the computation of standardised mortality ratios, along with 95% confidence intervals by the exact method.

The computations were performed with the data standardised in the six different settings of age and time-intervals defined before. The results showed to be very similar; for instance, the SMR ranged from 0.6217 in a 5x10 setting to 0.6448 in a 1x5 setting. To maintain a uniform format, from now onwards, the interpretations will be based on the results reached with a 5x1 configuration, that is, 5-year age classes and 1-year intervals. The other results are presented in the Appendix.

An **overall standardised mortality ratio** of **0.6236** suggests a substantially and significantly lower mortality of Portuguese football players compared with the general Portuguese male population ($p < 0.05$). The corresponding 95% confidence interval is [0.5221; 0.7390], that is, if the study was repeated many times using samples from the same population, the true SMR would be expected to fall within that interval in 95% of the times (Klugman et al., 2008).

Overall mortality according to the players' positions was observed to be lower than that of the general population for all four categories (SMR<1), although marginally not significant in the case of midfielders ($p = 0.0532$).

	SMR	95% CI for SMR	p-value
Overall	0.6236	0.5221 – 0.7390	0.0000
Goalkeepers	0.5582	0.3124 – 0.9206	0.0188
Defenders	0.5696	0.3921 – 0.7999	0.0005
Midfielders	0.7186	0.4976 – 1.0041	0.0532
Forwards	0.6285	0.4680 – 0.8263	0.0004

Table 4.2 –SMR for Portuguese football players, 95% CI and p-value: overall and stratified by position

Categorising deaths in 10-year age classes, SMR obtained are all lower than 1, which reveals consistency across age (Figure 4.1). For instance, the SMR for the 60-69 age class is 0.6037 (95% CI: 0.3868 – 0.8983; p =0.01), meaning that it was observed an actual number of deaths 39.63% lower than the expected. However, the SMR of the 50-59 and 70-79 age classes are non-significant (p>0.05).

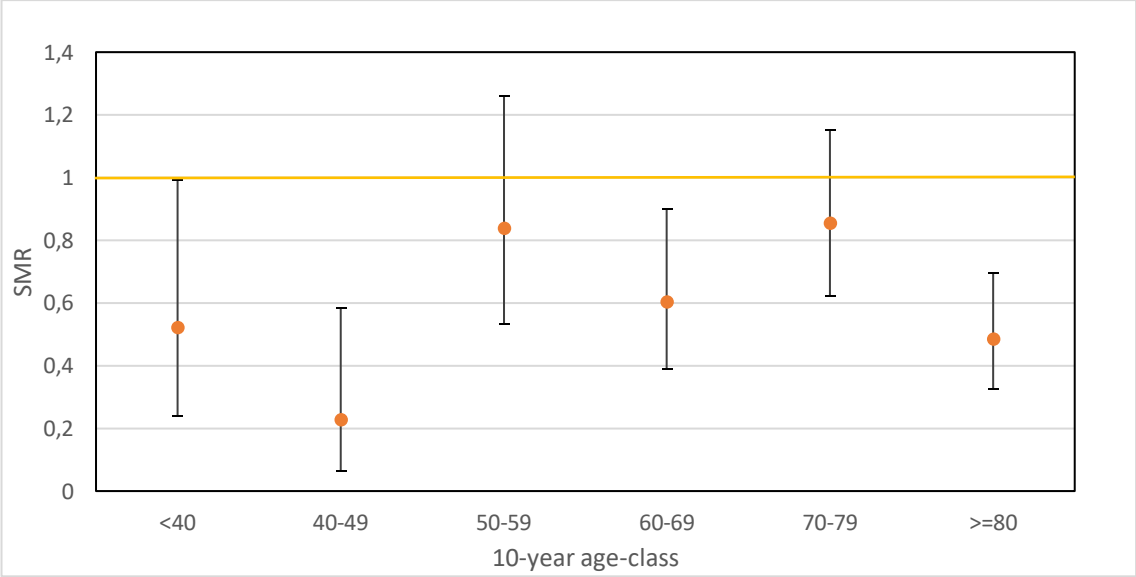

Figure 4.1– SMR for Portuguese football players by 10-year age class and respective 95% CI

The period effect was evaluated using two complementary approaches. First, deaths that occurred within each of the calendar periods 1921-1952, 1953-1973, 1974-1994, 1995-2015, were considered and the respective SMR and 95% CI estimated (Table 4.3). A lower mortality of players, when compared with the general male population, was observed across the periods, except the first one, 1921 – 1952, in whom a non-significant SMR of 1.29 was obtained. Among the nine deceased players in this period, three causes of death are known, including septicemia, food poisoning and complications following an eyes disorder.

Period	Actual deaths	Expected deaths	SMR	95% CI	p-value
1921-1952	9	6.97	1.29	0.59 – 2.45	0.53
1953-1973	13	22.19	0.59	0.31 – 1.00	0.05
1974-1994	49	64.34	0.76	0.56 – 1.01	0.06
1995-2015	62	119.78	0.52	0.40 – 0.66	0.00

Table 4.3– Standardised mortality ratio over time (four periods) for Portuguese football players

In the second method to account for mortality trends over time, the same calendar periods were considered, with the difference being the allocation of the players according to the date of the first match played in the national team. Among the players who have represented Portugal for the first time between 1921 and 1952, 88 have already died by 31 December 2015. In this scenario, the standardisation process estimates that 124.54 individuals die until the end of the investigation, yielding a SMR of 0.7066 (CI: 0.5667-0.8706). Of the 121 and 163 footballers who played for the first time in the 1953–1973 and 1974–1994 periods, respectively, 38 and 7 had died by 31 December 2015, yielding SMRs of 0.5640 (CI: 0.3991-0.7741) and 0.3588 (CI: 0.1443-0.7393). All estimated SMR were statistically significant ($p<0.05$). Since only the youngest are considered in the last period, 1995-2015, no death was recorded in this group.

For simplicity, in the estimation of Kaplan-Meier observed survival function of Portuguese football players, follow-up was defined as: age at exit from study - age at entry into study. The estimation of expected survival was performed using the three methods presented in section 3.2.2, considering 1-year intervals from $t = 0$ to $t = 77$ (last follow-up). Hakulinen and Ederer II curves are very similar, and the last one was chosen to be illustrated in Figure 4.2, along with the observed survival curve.

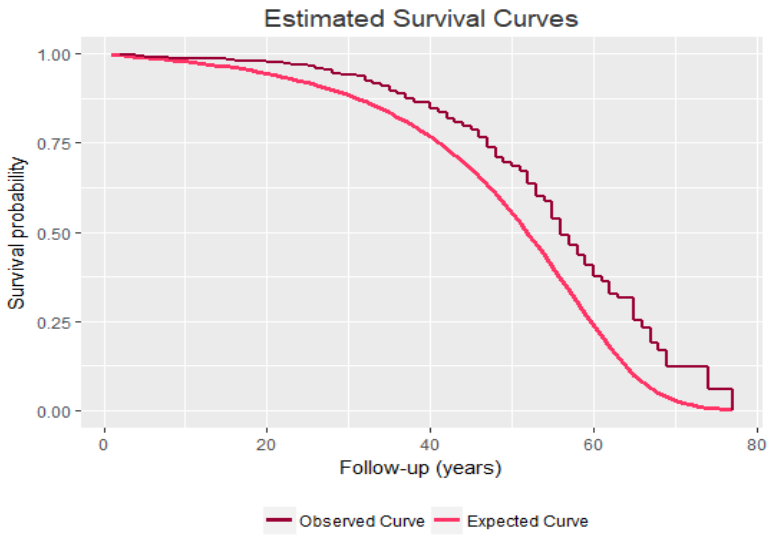

Figure 4.2 – Portuguese football players observed and expected survival curves

The observed curve is generally above the expected curve, shifting to the right early in the follow-up period and widening the gap until the end of follow-up. The difference between the curves is statistically significant. This strengthens the conclusion of greater survival of Portuguese football players when compared to the standard population.

Besides, observed and expected survival probability is also estimated considering age in x-axis, instead of follow-up time. Following Andersen (2013), the determination of life years saved/lost is based on the lifetime distribution function $F_x(t) = {}_tq_x = 1 - S_x(t)$, which represents the probability that a life aged x dies before attaining age $x + t$. The area below the observed distribution function (at each age) estimates the average number of life years lost from the time of first representation of National Team until the age of 99. Likewise, the average number of years lost by the counterparts of the athletes in the general population is calculated by the area under the expected distribution function. Then, the lower risk of death of the Portuguese football players is estimated by the difference between the two areas. Numerically, the players cohort saved on average 5.73 years of life in relation to the general population, until the final age point of 99 years-old.

Notice that the result would be the same using survival distributions – the number of years saved would continue to be estimated by the area between the two curves. In this case, the area under each curve would be interpreted as the temporary life expectancy.

Cox Proportional Hazard Models were used to evaluate the association between player position on the field, and total number of games, with overall mortality. Several models were developed using different time scales and adjustment for confounders (age at first match, year of birth and/or period of participation). Models using follow up as the time scale are included in the Appendix. The results in this section were obtained considering age as the time scale, with players entering the analysis at the age of first representation of the National Team (left-truncation) and exiting at their death/censoring age. Consequently, every model was adjusted for age.

In Table 4.4 are summarized the results for number of games in the entire career, which are treated as a categorical variable after application of decision trees. Model G.1 is only adjusted for age, while model G.2 is additionally adjusted for calendar period of participation (allocation by year of first representation). The category of number of games ≤134 and the calendar period 1921–1952 were chosen to be kept in the baseline, since are convenient levels for interpretation of results, besides having a higher observed death rate.

	Hazard Ratio (95% CI)	
	Model G.1	Model G.2
N. Games]134,366]	0.53 (0.36 – 0.78)	0.63 (0.42 – 0.92)
N. Games > 366	0.82 (0.47 – 1.43)	1.34 (0.74 – 2.44)
PP 1953-1973		0.49 (0.32 – 0.75)
PP 1974-2015		0.22 (0.09 – 0.53)

Table 4.4 – Cox proportional hazard ratios and 95% CI for number of games (model G.1 – adjusted for age; model G.2 – adjusted for age and period of participation) for Portuguese football players.

Table 4.5 displays the results for player position, with Model P.1 being adjusted for age and Model P.2 being adjusted for age and calendar period of participation. Likewise, 1921–1952 period is kept in the baseline, as well as forwards, which were chosen as the reference group due to the higher observed death rate.

	Hazard Ratio (95% CI)	
	Model P.1	Model P.2
Defenders	0.84 (0.54 - 1.31)	1.01 (0.64 – 1.58)
Goalkeepers	0.86 (0.48 - 1.53)	0.90 (0.51 – 1.61)
Midfielders	1.04 (0.67 - 1.61)	1.27 (0.81 – 1.98)
PP 1953-1973		0.50 (0.33 – 0.75)
PP 1974-2015		0.24 (0.10 – 0.55)

Table 4.5 – Cox proportional hazard ratios and 95% CI for position on the field (model P.1 – adjusted for age; model P.2 – adjusted for age and period of participation) for Portuguese football players.

Table 4.6 includes multivariate models for number of games and player position analysed simultaneously.

	Hazard Ratio (95% CI)	
	Model GP.1	Model GP.2
N. Games]134,366]	0.52 (0.35 – 0.77)	0.60 (0.41 – 0.89)
N. Games > 366	0.80 (0.45 – 1.42)	1.30 (0.71 – 2.37)
Defenders	0.90 (0.58 – 1.41)	1.03 (0.66 – 1.62)
Goalkeepers	0.93 (0.52 – 1.65)	0.92 (0.52 – 1.65)
Midfielders	1.16 (0.74 – 1.81)	1.37 (0.87 – 2.16)
PP 1953-1973		0.47 (0.31 – 0.72)
PP 1974-2015		0.21 (0.09 – 0.51)

Table 4.6 – Cox proportional hazard ratios and 95% CI for multivariate models including number of games and position on the field (model GP.1 – adjusted for age; model GP.2 – adjusted for age and period of participation) for Portuguese football players

From all the models it can be concluded that position played is not a significant predictor of mortality of Portuguese football players (CI for all models include the value 1).

Players in specific positions have different physical profiles and anthropometric characteristics. For example, the midfielders run the longest distances compared to forwards or defenders (Vigne *et al.*, 2010). Defenders have more body fat than forwards and midfielders. Forwards are the quickest players in the team. Goalkeepers tend to be the tallest and have a better performance on explosive power tests than players in the field (Sporis *et al.*, 2009). However, this work suggests that these distinct characteristics, besides others not mentioned, are not enough to lead to differences in mortality according to position for Portuguese football players. This result contrasts, for instance, with the higher mortality, and particularly higher cardiovascular disease rates, of NFL linemen players when compared to other positions, mainly due to their higher BMI. Also, isometric training, which is an important component of linemen's training regimen, has been shown to result in significant structural remodeling of the heart (Baron *et al.*, 2012). On the other side, football players have similar training preparations regardless the position on the field.

Players with a total number of games between 135 and 366 exhibit decreased mortality when compared to players with less than 135 games (baseline), ranging from 37% lower mortality in the Cox model for number of games adjusted for age and period of participation (model G.2), to 48% lower mortality in the multivariate model having number of games and position as covariates and controlling for age (model GP.1). However, players with more than 366 games in their career do not verify a survival advantage in relation to players with less than 135 games. This result seems to indicate that a longer football career is beneficial for longevity up to a certain threshold.

4.2 Mortality of Spanish Football Players

4.2.1 Data collection and statistical analysis

Data on Spanish football players who have represented their national team, for the 1920-2014 period, was collected mainly from the Real Federación Española de Fútbol (http://www.sefutbol.com/jugadores) and from a very complete website with the required statistics (http://www.bdfutbol.com/), being completed with other sources (https://eu-football.info/, http://www.national-football-teams.com/).

The procedures applied were the same as for the Portuguese players, with a few modifications, mentioned when necessary.

From the 751 football players who have represented at least once the Spanish national team, only 7 were excluded due to unknown date of death. In contrast with the Portuguese case, there was more information available. Among the remaining 744 footballers, 275 were known to have died by 31 December 2014.

The follow-up for each player was defined by the difference between the date of endpoint (31 December 2014 if alive; otherwise, the date of death) and the date of his first match representing the Spanish football team. Notice that the end of study is 31 December 2014, one year earlier than the Portuguese date, according to the availability of data in HMD.

The summary statistics for the players followed from 1920 to 2014, corresponding to years of birth between 1889 and 1995, are listed in Table 4.7.

Total number of players	744
Alive at 31 December 2014	469 (63%)
Dead at 31 December 2014	275 (37%)
Age at the first representation (mean±SD)	23.88 (± 2.85)
Age at the end of the study, for the players still alive	51.53 (± 16.75)
Age at death (mean±SD)	69.19 (± 16.10)
Number of games played by the national team (mean±SD)	12.09 (± 20.15)
Number of games played in the entire football career (mean±SD)	283.6 (± 152.80)
Goalkeepers	49
Defenders	231
Midfielders	229
Forwards	235

Table 4.7 - Characteristics of Spanish Football Players (1920-2014 period).
Sources: Rfef; *Bdfutbol; national-football-teams and eu-football.info*

The overall mortality of Spanish players was compared with that of the Spanish male population, using the Human Mortality Database.

For Spain, there was no need to use cohort data, since period life tables were available from 1908 onwards and the national team's debut was in 1920.

4.2.2 Results

In a similar way to the previous section, mortality of the Spanish football players was primary compared with the Spanish male population through the computation of standardised mortality ratios, along with 95% confidence intervals.

Likewise, the computations were performed with the data standardised in the six different settings of age and time-intervals defined before. The results showed to be very similar, with SMR varying between 0.9399 in a 5x10 setting and 0.9486 in a 1x1 setting. To maintain a uniform format, from now onwards, interpretations will be based on the results reached with a 5x1 configuration, that is, 5-year age classes and 1-year intervals. The other results are presented in the Appendix.

An overall SMR of **0.9416** was obtained for the Spanish football players, that is, it is estimated that this group of elite athletes have a **5.84% lower mortality** than the Spanish standard population. However, the verified mortality difference based on SMR is not statistically significant at 5%, since the p-value is 0.3327. Indeed, the 95% confidence interval for SMR, [0.8336; 1.0597], contains the value 1. Therefore, the hypothesis of similar mortality of the Spanish football players with the general population is not rejected.

Regarding the position played, the SMR are lower than 1, except for forward players. Again, the results are not statistically significant at 5%. Nevertheless, goalkeepers stand out with a p-value of 5.79%, meaning that, at 90% confidence level (α=10%), the SMR of 0.6484 would be significant.

	SMR	**95% CI for SMR**	**p-value**
Overall	0.9416	0.8336 – 1.0597	0.3327
Goalkeepers	0.6484	0.3904 – 1.0125	0.0579
Defenders	0.9052	0.7132 – 1.1330	0.4189
Midfielders	0.9596	0.7736 – 1.1768	0.7417
Forwards	1.0613	0.8512 – 1.3075	0.6055

Table 4.8 –SMR for Spanish football players, 95% CI and p-value: overall and stratified by position

The SMR by age-class (Figure 4.3) confirm that there is no statistical evidence of difference in mortality between players and its standard population (CI including the value 1). However, notice that the estimated SMR are lower than 1 for younger age-classes and greater than 1 for groups above 70 years-old. Once more, some of these results would be significant at 90% confidence level. For instance, for the 40–49 age group it is obtained a 0.61 SMR with a corresponding p-value of 6.35%.

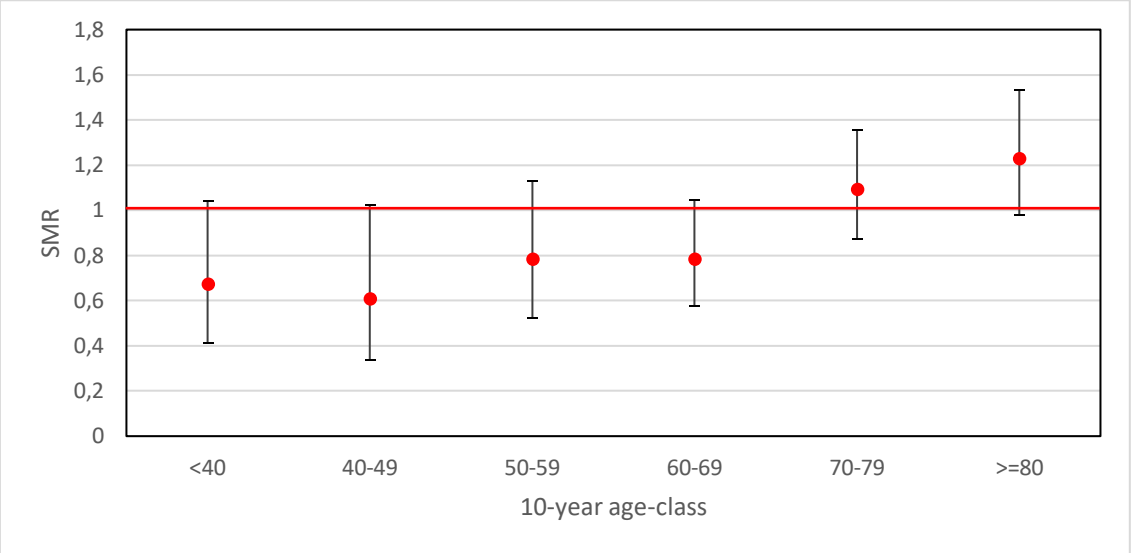

Figure 4.3– SMR for Spanish football players by 10-year age class and respective 95% CI

The period effect was evaluated using two complementary approaches. First, deaths that occurred within each of the calendar periods 1920–1935, 1936–1955, 1956–1975, 1976–1995, 1996–2014, were considered and the respective SMR and 95% CI estimated (Table 4.9).

Period	Actual deaths	Expected deaths	SMR	95% CI	p-value
1920-1935	8	6.31	1.2674	0.5472 – 2.4972	0.6000
1936-1955	13	24.52	0.5302	0.2823 – 0.9066	0.0165
1956-1975	43	50.76	0.8472	0.6131 – 1.1412	0.3076
1976-1995	107	97.52	1.0973	0.8992 – 1.3259	0.3613
1996-2014	104	112.96	0.9207	0.7523 – 1.1156	0.4295

Table 4.9– Standardised mortality ratio over time (five periods) for Spanish football players

It was only in the 1936–1955 period that the SMR was statistically different from 1, being estimated a 46.98% lower mortality of Spanish players. This might be associated with the higher death rates of the Spanish general population as a consequence of the Civil War (1936–1939), a period of conflict and massive violence. It is even known that many players departed the country, mostly from Catalonia and Basque Country, regions facing Francisco Franco repression. For instance, in 1937, FC Barcelona undertook a tour of games in America, including Mexico and USA, to escape a country in war as well as to raise funds for the club (Fútbol Club Barcelona - Official Website). In the same way, Athletic Bilbao, a team allowing only Basque-born players, took part in a tour of matches throughout Europe, the Soviet Union and America. Although speculative, the Civil War might have contributed to the observed

lower mortality of Spanish football players in comparison to the general population, since they were not affected by the events in terms of mortality.

In the second approach to account for mortality trends over time, players were allocated to a period according to the date of their first representation of the Spanish National Team. The first three calendar periods were the same as in the first method, but the last two periods were joined, since only one death occurred among the players who first represented Spain between 1996 and 2014 and the result would not be meaningful. Apart from the 1920–1935 period, all SMR were lower than 1, however, statistical evidence does not reject the hypothesis of identical mortality between the Spanish football players and the Spanish general population for each period.

The observed Kaplan-Meier survival curve was estimated, considering follow-up in x-axis. The expected survival, based on the Spanish general male population death rates, was determined through both Ederer II and Hakulinen methods, giving similar results. To keep consistency, the graph of Ederer II is illustrated, as well as the observed curve, in Figure 4.4.

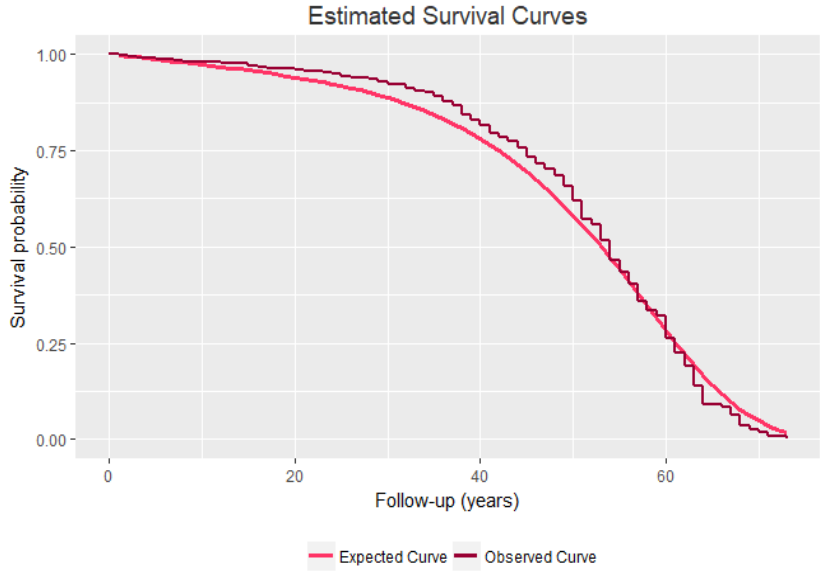

Figure 4.4 – Spanish football players observed and expected survival curves

In opposition to the Portuguese case, the observed survival curve does not lie entirely above the expected survival. It happens at the beginning, but as time increases, the gap between the curves progressively narrows, until $t = 54$, when the curves start crossing each other. The expected survival is superior at the end of the follow-up (from $t = 63$ onwards).

The years lost method is applied using the same approach as in the Portuguese case study. However, in the Spanish framework, the observed and expected survival curves, estimated using age in x-axis, cross each other. Clearly, the same occurs with the lifetime distribution functions. Therefore, some ages will contribute to years saved, while others to

years lost. At the end, Spanish football players saved on average 1.76 years of life in comparison to the Spanish general population, until 98 years-old. This value is much lower than the one obtained for Portuguese players.

Cox Proportional Hazard Models were again used to evaluate the association between player position on the field, and total number of games, with overall mortality. The results in this section were obtained considering age as the time scale, where players enter the analysis at the age of first representation of the National Team (left-truncation) and exit at their death/censoring age. Therefore, every model is adjusted for age. Models using follow up as the time scale were also developed, with adjustments for age at first match and year of birth, which are included in the Appendix.

Table 4.10 shows the results for the number of games in the entire career, which was transformed into a categorical variable through the application of decision trees. Model G.3 is only adjusted for age, while Model G.4 is additionally adjusted for year of birth. Players with less than 199 games were chosen as the reference group since they have the higher observed death rates.

	Hazard Ratio (95% CI)	
	Model G.3	Model G.4
N. Games]198,350]	0.54 (0.41 – 0.70)	0.77 (0.55 – 1.07)
N. Games > 350	0.33 (0.20 – 0.54)	0.55 (0.31 – 0.96)
Birth Year		0.98 (0.97 – 0.99)

Table 4.10 – Cox proportional hazard ratios and 95% CI for number of games (model G.3 – adjusted for age; model G.4 – adjusted for age and year of birth) for Spanish football players.

Regarding the position on the field, midfielders are kept in the baseline, also due to the higher observed death rate. Model P.3 is adjusted for age and Model P.4 is adjusted for age and year of birth (Table 4.11).

	Hazard Ratio (95% CI)	
	Model P.3	Model P.4
Forwards	1.10 (0.82 – 1.47)	1.23 (0.91 – 1.66)
Defenders	0.89 (0.66 – 1.21)	1.04 (0.77 – 1.42)
Goalkeepers	0.58 (0.35 – 0.96)	0.65 (0.39 – 1.07)
Birth Year		0.97 (0.97 – 0.98)

Table 4.11 – Cox proportional hazard ratios and 95% CI for position on the field (model P.3 – adjusted for age; model P.4 – adjusted for age and year of birth) for Spanish football players.

Table 4.12 includes multivariate models for number of games and player position analysed simultaneously.

	Hazard Ratio (95% CI)	
	Model GP.3	Model GP.4
N. Games]198,350]	0.53 (0.4 – 0.69)	0.75 (0.53 – 1.04)
N. Games > 350	0.33 (0.2 – 0.54)	0.55 (0.31 – 0.96)
Forwards	1.29 (0.96 – 1.74)	1.29 (0.96 – 1.74)
Defenders	0.99 (0.73 – 1.34)	1.05 (0.77 – 1.43)
Goalkeepers	0.69 (0.42 – 1.14)	0.68 (0.41 – 1.13)
Birth Year		0.98 (0.97 – 0.99)

Table 4.12 – Cox proportional hazard ratios and 95% CI for multivariate models including number of games and position on the field (model GP.3 – adjusted for age; model GP.4 – adjusted for age and year of birth) for Spanish football players

Results show that the number of games in the career of a Spanish football player influences their survival. Hazard ratios adjusted for age indicated a lower mortality for players with a greater number of games: 0.54 and 0.53 HR for players with number of games belonging to]198, 350] in, respectively, univariate (G.3) and bivariate (GP.3) models, when compared to the baseline; 0.33 HR for number of games > 350 in relation to the baseline group, both in univariate and bivariate models (G.3 and GP.3). These lower mortality risks remained after adjusting for year of birth, but with less pronounced hazard ratios, whereas the hazard ratio for players with number of games belonging to]198,350] became non-significant. The observed significant reduction of mortality for players with greater number of games in their curriculum underpins the findings of beneficial effects in longevity of sustained and strenuous competition.

Comparing the mortality of forwards, defenders and goalkeepers with midfielders, it was not seen, in general, a mortality difference. The only exception was goalkeepers in model P.3 (Table 4.11), showing a 42% lower mortality compared to midfielders. However, this survival advantage was not reached in any other model, even considering follow up as the time scale (see Appendix). This result is in line with the Portuguese study, reinforcing the idea that the position on the field is not a determinant factor for mortality of football players.

4.3 Comparing the mortality of Portuguese and Spanish football players

The previous computations of Portuguese and Spanish football players are based on different standard populations; therefore, the results (e.g., standardised mortality ratios) are not comparable.

To this end, a common standard population should be chosen to compare the mortality of the two populations under study, and then the DSMR and ISMR can be determined. In this case, the standardisation process was done only by age (5-year age groups), providing a meaningful comparison of the age-specific mortality rates of each population.

First, it was used the Spanish general population as the standard and, afterwards, the population of the Portuguese and Spanish football players were pooled to create a standard population. The relevant measures are illustrated in Table 4.13.

	Standard Population	
	Spanish general population	Pooled population
CMR standard population	0.0111	0.0096
DSMR Portuguese players	0.0055	0.0080
DSMR Spanish players	0.0076	0.0108
ISMR Portuguese players	0.0065	0.0079
ISMR Spanish players	0.0088	0.0108

Table 4.13 – Single figure measures of mortality (CMR, DSMR and ISMR) for Spanish and Portuguese football players based on two different standard populations.

In both approaches, the DSMR as well as the ISMR are greater for the Spanish cohort of football players than for the Portuguese cohort. The ratio of DSMR of the Portuguese to the Spanish cohort is 0.7199 and 0.7371 in first and second approaches; while the ratio of ISMR is 0.7353 and 0.7336, respectively. Consequently, the single figure measures show a higher mortality for the Spanish football players compared to the Portuguese football players, after adjusting for age.

This latter difference as well as the results concerning the SMR required further clarification and motivated the comparison of the life expectancy at birth between the Spanish and Portuguese general populations, using available data in the HMD.

For the 1940–2014 period, it was found that the life expectancy at birth is higher for the Spanish population in relation to the Portuguese population for every year (apart from 1940 and 1941), as illustrated in Figure 4.5.

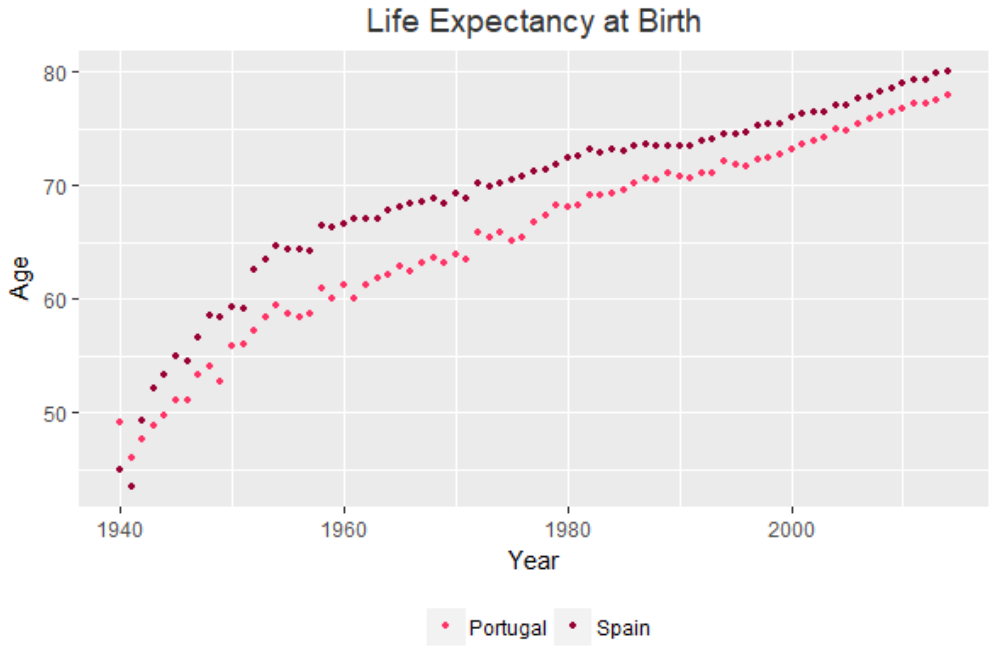

Figure 4.5 – Life expectancy at birth for Portuguese and Spanish general population (1940-2014).

Thus, the survival advantage of the Portuguese football players in comparison to the Spanish football players, combined with the lifespan advantage of the Spanish general population is a possible reason for the significant lower mortality of the Portuguese football players in comparison to its standard population, a phenomenon not observed for the Spanish players. Nevertheless, further investigation is needed to justify the differences.

Chapter 5 – Conclusion

In the context of recent concerns regarding potential negative health effects of high-level physical exercise, research on the mortality of elite athletes is of particular interest. A comprehensive literature review was undertaken, with the vast majority of the studies concluding that top-level athletes live longer than the general population, even if a few indicated that these mortality differences are not significant.

Trying to provide a meaningful contribution to the topic, a search on Portuguese elite athletes (for which no mortality study was found) was performed. However, only information on football players was available. Actually, collecting the data was notably the most time-consuming stage, including the compilation of the information in a data base. It was then possible to analyse mortality of Portuguese football players who have already represented the National Team at least once in their professional career, during the period from 1921 to 2015. In order to have a more complete study, the Spanish Football players' mortality was also investigated for the 1920-2014 period.

This study shows that playing football at an elite level does not increase overall mortality or shorten lifespan.

For Spanish football players, it was not observed a mortality difference compared with the Spanish reference population. However, it should be highlighted that there was a significant reduction in the mortality ratio for the 1936-1955 period. Although speculative, this may be correlated to the Spanish Civil War, as already elucidated.

The results were more significant in the case of Portuguese football players, with an average of 5.73 years of life saved and a 37.64% overall lower mortality when compared to the general Portuguese population. This reduction in overall mortality was consistent across age-groups, time periods (except for deaths allocated to the 1921-1952 period) and position on the field. The difference between the observed and the expected survival curves since the beginning of follow-up illustrated the football players' survival advantage over the general population.

The findings on Portuguese football players are in line with the study of Taioli (2007), who estimated a significant 32% lower mortality for football players enrolled in the Italian A and B professional leagues between 1975 and 2003.

There was not found a significant difference in mortality according to the position the players occupy in the field, both for the Portuguese and Spanish cohorts. On the contrary, it seems that an increasing number of games in the career generally contributed to lower

mortality. Usually, these athletes are the fittest and also less frequently injured, reinforcing the contributions to longevity of a high physical level.

The cohorts of Portuguese and Spanish football players were also compared through direct and indirect standardisation methods and a clear gap in mortality discriminates both populations, with a survival advantage for Portuguese athletes. Even though genetic background, social and environmental factors may differ, it seems likely that the characteristics of such athletes are broadly comparable across these nationalities. Therefore, further research is needed to clarify the difference. For example, data on the lifestyle habits after their professional career would have been informative to study the impact on mortality.

The higher expectancy at birth of the Spanish general population in relation to the Portuguese population, combined with the aforementioned survival advantage of the group of Portuguese football players justify, partially, the findings in this study: a significant lower mortality of Portuguese players contrasting with no mortality difference of Spanish players in comparison to their respective standard population.

Although this essay provided a main contribution to the field by a complete mortality overview of the Portuguese and Spanish football players, it has its limitations. Firstly, it was not possible to validate the dates of death via official national sources. Secondly, it was necessary to exclude football players for whom the date of death is unknown, especially in the case of Portugal, accounting for 10% of the population under study. However, these deaths correspond mainly (97%) to individuals whose first game representing the National Team occurred before 1953, and the SMR analysed separately for the periods of participation 1953-1973, 1974-1994 and 1995-2015 were significantly smaller than one, confirming the substantial reduction in overall mortality.

Besides analysing overall mortality of elite athletes, studying the specific causes of death allow a better understanding of the long-term risks and benefits on their longevity. For instance, Marijon *et al.* (2013) estimated a 41% lower mortality for Tour de France French cyclists, for which contributed a significant reduction in mortality for neoplasms, cardiovascular diseases, respiratory system diseases and digestive system diseases. Nevertheless, according to the study of Lehman *et al.* (2012), despite the lower overall mortality of retired NFL players, they have a higher neurodegenerative mortality. Even similar overall mortality between elite athletes and the reference population comprised reduced mortality for cancer and an increased mortality due to external causes in power Finnish athletes (Sarna *et al.*, 1993). Unfortunately, mortality by cause of death was not available for most Portuguese and Spanish football players, making it impossible to develop a similar study for these athletes.

Analysing mortality of football players from other countries could provide insight to the results obtained in this work. Future research could also focus on assessing mortality of different sports, as well as including women elite athletes, since there is a current paucity of studies assessing their longevity. Again, available data is necessary to perform this investigation.

A possible field of further research could be the development of insurance products specifically designed to elite athletes. Analysing their mortality and morbidity risks accurately is therefore crucial in this area.

As a final comment, following the opinion of Sanchis-Gomar *et al.* (2011), "physicians, health professionals and general population should not hold the impression that strenuous exercise and/or high level aerobic competitive sports have deleterious effects, are bad for one's health, and shorten life". However, it should be noted that the elite level of physical activity is not a plausible and reasonable goal for most people. Hence, the final general recommendation should be to practice exercise regularly, ideally prescribed and supervised by a professional in the area – "Even a little is good; a lot is better if you are well trained" (Sanchis-Gomar *et al.*, 2011).

Appendix

A. Hypothesis test for the standardised mortality ratio

Besides estimating the SMR, one question of interest is its statistical significance. The test statistic is derived from the usual assumption that, under the null hypothesis (H_0: SMR=1), the number of deaths, denoted by the random variable D, follows a Poisson distribution with mean equal to the expected number of deaths, $\hat{\mathrm{E}} = \sum_{j=1}^{M} E_j \, {}^{s}m_j$. It is assumed that $\hat{\mathrm{E}}$ is based on a sufficiently large sample, so that it can be taken as a constant (Breslow and Day, 1987).

Defining *d* as the observed number of deaths and noticing that it is a two-side test, the exact p-value is calculated in the following way:

$$If d < \hat{\mathrm{E}}: p = min\left\{2 \times \sum_{k=0}^{d} \frac{e^{-\hat{\mathrm{E}}} \times \hat{\mathrm{E}}^{k}}{k!}, 1\right\} \tag{29}$$

$$If d > \hat{\mathrm{E}}: p = min\left\{2 \times \left(1 - \sum_{k=0}^{d-1} \frac{e^{-\hat{\mathrm{E}}} \times \hat{\mathrm{E}}^{k}}{k!}\right), 1\right\} \tag{30}$$

Byar (Breslow and Day, 1987) suggested an extremely accurate approximation to the exact Poisson test, based on the asymptotic Normal Distribution of the test-statistic:

$$T = 3\sqrt{D'}\left[1 - \frac{1}{9D'} - \left(\frac{\hat{\mathrm{E}}}{D'}\right)^{1/3}\right] \overset{a}{\sim} N(0,1) \quad , \tag{31}$$

where $D' = d + 1$ if $d < \hat{\mathrm{E}}$ and $D' = d$ if $d > \hat{\mathrm{E}}$, in the observed value of T.

Consequently, the approximate p-value is obtained by:

$$If d < \hat{\mathrm{E}}: p = \min\left\{2 \times \Phi\left(3\sqrt{d+1}\left[1 - \frac{1}{9(d+1)} - \left(\frac{\hat{\mathrm{E}}}{d+1}\right)^{\frac{1}{3}}\right]\right), 1\right\} \tag{32}$$

$$If\ d > \hat{\mathrm{E}}: p = \min\left\{2 \times \left(1 - \Phi\left(3\sqrt{d}\left[1 - \frac{1}{9d} - \left(\frac{\hat{\mathrm{E}}}{d}\right)^{\frac{1}{3}}\right]\right)\right), 1\right\} \tag{33}$$

B. Confidence Interval for the standardised mortality ratio

A statistical question of interest is the determination of a (1-α) confidence interval for the true value of SMR, where α is the selected significance level. If the study were to be repeated many times, using the same method to select different samples from the population, the true SMR would be expected to fall within the interval estimates in (1-α) % of the cases.

In practice, the exact confidence interval for the SMR is determined by first finding lower (μ_L) and upper (μ_U) limits for the mean $\mu = E[D]$, and then computing $\text{SMR}_L = \frac{\mu_L}{\hat{E}}$ and $\text{SMR}_U = \frac{\mu_U}{\hat{E}}$. Based on Liddell (1984), the lower and upper limits satisfy, respectively, the following equations:

$$P(D \geq d \mid \mu = \mu_L) = \frac{\alpha}{2} \tag{34}$$

$$P(D \leq d \mid \mu = \mu_U) = \frac{\alpha}{2} \tag{35}$$

These are quite simple to solve considering the relationship between the Poisson and χ^2 distributions (Fisher, 1935): the sum of the terms of the Poisson series with parameter μ up to but excluding the term c is equal to the survival probability of a χ^2 distribution with $2c$ degrees of freedom evaluated at the value 2μ. More formally:

$$P(D < c) = P\left(\chi^2_{(2c)} > 2\mu\right) \tag{36}$$

Rearranging relationship (36), two more expressions are obtained:

$$P(D \geq c) = 1 - P\left(\chi^2_{(2c)} > 2\mu\right) \tag{37}$$

$$P(D \leq c) = P\left(\chi^2_{(2c+2)} > 2\mu\right) \tag{38}$$

Consequently, the upper and lower limits are found as follows:

Lower limit: find μ_L such that $P\left(\chi^2_{(2d)} > 2\mu_L\right) = 1 - \frac{\alpha}{2}$ (39)

Upper limit: find μ_U such that $P\left(\chi^2_{(2d+2)} > 2\mu_U\right) = \frac{\alpha}{2}$ (40)

Alternatively, for large d, an approximate method can be used, based on the standardised normal test statistic (31) suggested by Byar (Breslow and Day, 1987). For a (1-α) confidence interval, the approximate limits for the mean are:

$$\mu_L = d\left(1 - \frac{1}{9d} - \frac{z_{\alpha/2}}{3\sqrt{d}}\right)^3 \tag{41}$$

$$\mu_U = (d+1)\left(1 - \frac{1}{9(d+1)} + \frac{z_{\alpha/2}}{3\sqrt{d+1}}\right)^3 \tag{42}$$

As an illustration, consider that $d = 51$ deaths occurred in a population while Ê=81.15 would have been expected applying the mortality rates of some standard population, which yields a SMR of 0.6285. The 95% confidence interval requires α=0.05.

Applying the exact procedure, for the lower and upper limits, the degrees of freedom of the χ^2 distribution are, respectively, 102 and 104. The critical values in (39) and (40) are found using a calculator: $2\mu_L = 75.9457 \Rightarrow \mu_L = 37.97285$ and $2\mu_U = 134.1112 \Rightarrow \mu_U = 67.05558$. Consequently, $\text{SMR}_L = \frac{37.97285}{81.15} = 0.4679$ and $\text{SMR}_U = \frac{67.05558}{81.15} = 0.8263$. That is, the 95% confidence interval for the standardised mortality ratio is [0.4679; 0.8263].

The approximate method shows to be accurate, giving the same SMR (4 decimal places).

C. SMR and 95% CI for every setting of age/time-periods

Configuration (age x time)	Actual deaths	Expected deaths	SMR	95% CI	p-value
1x1	133	212.91	0.6247	0.523 - 0.7403	0.000
5x1	133	213.28	0.6236	0.5221 - 0.739	0.000
1x5	132	204.70	0.6448	0.5395 - 0.7647	0.000
5x5	132	205.56	0.6421	0.5373 - 0.7615	0.000
1x10	133	213.22	0.6238	0.5223 - 0.7392	0.000
5x10	132	213.93	0.6217	0.5205 - 0.7368	0.000

Table C.1 – SMR, 95% CI and p-value for Portuguese football players

Configuration (age x time)	Actual deaths	Expected deaths	SMR	95% CI	p-value
1x1	275	289.92	0.9486	0.8397 – 1.0675	0.3987
5x1	275	292.06	0.9416	0.8336 – 1.0597	0.3327
1x5	275	290.12	0.9479	0.8392 – 1.0668	0.3922
5x5	275	292.25	0.9410	0.8330 – 1.0590	0.3273
1x10	275	290.52	0.9466	0.8380 – 1.0653	0.3794
5x10	276	292.58	0.9399	0.8321 – 1.0578	0.3180

Table C.2 – SMR, 95% CI and p-value for Spanish football players

D. Cox Proportional Hazard Models

	Hazard Ratio (95% CI)		
	Model 1	Model 2	Model 3
N. Games]134,366]	0.64 (0.44 – 0.95)		0.61 (0.41 – 0.91)
N. Games > 366	1.16 (0.64 – 2.11)		1.11 (0.61 – 2.02)
Defenders		1.04 (0.66 – 1.64)	1.06 (0.68 – 1.67)
Goalkeepers		1.03 (0.58 – 1.83)	1.02 (0.57 – 1.81)
Midfielders		1.35 (0.86 – 2.10)	1.45 (0.92 – 2.28)
PP 1953–1973	0.54 (0.36 – 0.83)	0.54 (0.36 – 0.82)	0.52 (0.34 – 0.80)
PP 1974–2015	0.25 (0.10 – 0.61)	0.26 (0.11 – 0.61)	0.24 (0.10 – 0.57)

Table D.1 – Cox proportional hazard ratios and 95% CI, using follow up as time scale, for Portuguese football players (model 1 – HR for number of games, adjusted for period of participation; model 2 – HR for position on the field, adjusted for period of participation; model 3 – HR for number of games and position on the field, adjusted for period of participation)

	Hazard Ratio (95% CI)		
	Model 1	Model 2	Model 3
N. Games]198,350]	0.78 (0.56 – 1.1)		0.75 (0.53 – 1.05)
N. Games > 350	0.56 (0.32 – 0.98)		0.55 (0.31 – 0.97)
Forwards		1.21 (0.9 – 1.63)	1.28 (0.94 – 1.72)
Defenders		1.04 (0.76 – 1.43)	1.05 (0.77 – 1.43)
Goalkeepers		0.67 (0.41 – 1.12)	0.70 (0.42 – 1.17)
Age at first match	1.07 (1.03 – 1.11)	1.07 (1.03 – 1.12)	1.08 (1.03 – 1.12)
Birth Year	0.98 (0.97 – 0.99)	0.97 (0.97 – 0.98)	0.98 (0.97 – 0.99)

Table D.2 – Cox proportional hazard ratios and 95% CI, using follow up as time scale, for Spanish football players (model 1 – HR for number of games, adjusted for age at first match and year of birth; model 2 – HR for position on the field, adjusted for age at first match and year of birth; model 3 – HR for number of games and position on the field, adjusted for age at first match and year of birth)

References

Abel EL and Kruger ML (2005). Longevity of Major League Baseball Players, *Research in Sports Medicine*, 13(1), 1–5.

Andersen PK (2013). Decomposition of number of life years lost according to causes of death, *Statistics in Medicine*, 32, 5278–285.

Antero-Jacquemin J, Pohar-Perme M, Rey G, Toussaint JF and Latouche A (2018). The heart of the matter: years-saved from cardiovascular and cancer deaths in an elite athlete cohort with over a century of follow-up, *European Journal of Epidemiology*, 33 (6), 531–43.

Baron SL, Hein MJ, Lehman E and Gersic CM (2012). Body Mass Index, Playing Position, Race, and the Cardiovascular Mortality of Retired Professional Football Players, *The American Journal of Cardiology*, 109, 889–96.

Beaglehole R and Stewart A (1983). The longevity of international rugby players, *The New Zealand Medical Journal*, 96, 513–15.

Belli S and Vanacore N (2005). Proportionate mortality of Italian soccer players: is amyotrophic lateral sclerosis an occupational disease?, *European Journal of Epidemiology*, 20, 237–42.

Breslow NE and Day NE (1987), "Rates and Rate Standardization", in *Statistical Methods in Cancer Research: Volume II—The Design and Analysis of Cohort Studies*, International Agency for Research on Cancer, Lyon: Oxford University press, 48–82.

Cox DR (1972). Regression Models and Life-Tables, *Journal of the Royal Statistical Society*, Series B (Methodological), Vol. 34, No. 2, 187-220.

Ederer F, Axtell LM and Cutler SJ (1961). The relative survival rate: a statistical methodology *National Cancer Institute Monograph*, 6, 101–21.

Ederer F and Heise H (1959). – The effect of eliminating deaths from cancer on general population survival rates, Methodological Note 11, End Results Evaluation Section, National Cancer Institute.

Fisher RA (1935). The mathematical distributions used in common tests of significance, *Econometrica*, 3, 353–65.

Fútbol Club Barcelona - Official Website. Available at:
https://www.fcbarcelona.com/club/history/card/1930-1939-struggling-against-history
Last accessed: August 2018.

Gajewski AK and Poznańska A (2008). Mortality of top athletes, actors and clergy in Poland: 1924–2000 follow-up study of the long term effect of physical activity, *European Journal of Epidemiology*, 23 (5), 335–40.

Hakulinen T (1982). Cancer survival corrected for heterogeneity in patient withdrawal, *Biometrics*, 38, 933–42.

Hurley B and Reuter I (2011). Aging, Physical Activity, and Disease Prevention, *Journal of Aging Research*, 2011, 1–2.

IFOA (2011). Core Reading: Subject CT4. The Actuarial Education Company, Institute and Faculty of Actuaries.

IFOA (2011). Core Reading: Subject CT5. The Actuarial Education Company, Institute and Faculty of Actuaries.

Kalist DE and Peng Y (2007). Does education matter? Major league baseball players and longevity, *Death Studies*, 31(7), 653–70.

Keiding N (1987). The method of expected number of deaths,1786-1886-1986. *International Statistical Review*, 55(1), 1 –20.

Klugman SA, Panjer HH and Willmot GE (2008), *Loss Models: From Data to Decisions*, 3rd ed., Hoboken NJ., John Wiley & Sons.

Knez WL, Coombes JS and Jenkins DG (2006). Ultra-endurance exercise and oxidative damage: implications for cardiovascular health, *Sports Medicine*, 36, 429–41.

Koning R, Matheson V, Nathan A and Pantano J (2014). The Long-Term Game: An Analysis of the Life Expectancy of National Football League Players, International Journal of Financial Studies, 2 (1), 168–178.

La Gerche A, Boyle A, Wilson AM and Prior DL (2004). No evidence of sustained myocardial injury following an Ironman distance triathlon, *International Journal of Sports Medicine*, 25 (1), 45–9.

La Gerche A, Burns AT, Mooney DJ, Inder WJ, Taylor AJ, Bogaert J, MacIsaac AI, Heidbüchel H and Prior DL (2012). Exercise-induced right ventricular dysfunction and structural remodelling in endurance athletes, *European Heart Journal, 33, 8 (April)*, 998–1006.

Laslett L, Eisenbud E and Lind R (1996). Evidence of myocardial injury during prolonged strenuous exercise, *The American Journal of Cardiology*, 78, 488–90.

Lee IM and Paffenbarger RS (2000). Associations of light, moderate, and vigorous intensity physical activity with longevity: The Harvard Alumni Health Study, *American Journal of Epidemiology*, 151, 3, 293–99.

Lehman EJ, Hein MJ, Baron SL and Gersic CM (2012). Neurodegenerative causes of death among retired National Football League players, *Neurology*, 79, 1970–974.

Liddell FDK (1984). Simple exact analysis of the standardised mortality ratio, *Journal of Epidemiology and Community Health*, 38, 85–88.

Lin Y, Gajewski A and Poznańska A (2016). Examining mortality risk and rate of ageing among Polish Olympic athletes: a survival follow-up from 1924 to 2012, *British Medical Journal Open*, 6:e010965.

Mann HB and Whitney DR (1947). On a test of whether one of two random variables is stochastically larger than the other, *The Annals of Mathematical Statistics*, 18, 50–9.

Marijon E, Tafflet M, Antero-Jacquemin J, El Helou N, Berthelot G, Celermajer DS, Bougouin W, Combes N, Hermine O, Empana J-P, Rey G and Toussaint J-F (2013). Mortality of French participants in the Tour de France (1947–2012), *European Heart Journal*, 34, 3145–150.

McKee AC, Cantu RC, Nowinski CJ, Hedley-Whyte ET, Gavett BE, Budson AE, Santini VE, Lee H, Kubilus CA and Stern RA (2009). Chronic traumatic encephalopathy in athletes: progressive tauopathy following repetitive head injury, *Journal of Neuropathology and Experimental Neurology*, 68(7), 709–35.

Pärssinen M, Kujala U, Vartiainen E, Sarna S and Seppälä T (2000). Increased premature mortality of competitive powerlifters suspected to have used anabolic agents, *International Journal of Sports Medicine*, 21, 225–27.

Pelliccia A, Kinoshita N, Pisicchio C, Quattrini F, Dipaolo FM, Ciardo R, Di Giacinto B, Guerra E, De Blasiis E, Casasco M, Culasso F and Maron BJ (2010). Long-Term Clinical Consequences of Intense, Uninterrupted Endurance Training in Olympic Athletes, *Journal of the American College of Cardiology*, 55, 1619–625.

Pokhrel A (2007), – Age-Standardization of Relative Survival Ratios, academic dissertation, University of Tampere, Finnish Cancer Registry.

Reynolds R and Day S (2012). Life Expectancy and Comparative Mortality of Major League Baseball players, 1900–1999. WebmedCentral SPORTS MEDICINE, 3(5): WMC003380.

Ribeiro CS (2014), *Econometria*, Lisboa, Escolar Editora.

Sanchis-Gomar F, Olaso-Gonzalez G, Corella D, Gomez-Cabrera MC and Vina J (2011). Increased Average Longevity among the "Tour de France" Cyclists, *International Journal of Sports Medicine,* 32, 644–47.

Sarna S, Kaprio J, Kujala UM and Koskenvuo M (1997). Health status of former elite athletes. The Finnish experience, *Aging Clinical and Experimental Research*, 9, 35–41.

Sarna S, Sahi T, Koskenvuo M and Kaprio J (1993). Increased life expectancy of world class male athletes, *Medicine and Science in Sports and Exercise*, 25, 2, 237-44.

Schnohr P (1971). Longevity and causes of death in male athletic champions, *Lancet*, 298 (7738), 1364-366.

Sporis G, Jukic I, Ostojic SM and Milanovic D (2009). Fitness profiling in soccer: physical and physiologic characteristics of elite players, *Journal of Strength and Conditioning Research*, 23, 1947–953.

Taioli E (2007). All causes mortality in male professional soccer players, *European Journal of Public Health*, 17(6), 600–04.

Therneau T and Offord J (1999), – Expected Survival Based on Hazard Rates, Technical Report No. 63, Section of Biostatistics, Mayo Clinic.

Vigne G, Gaudino C, Rogowski I, Alloatti G and Hautier C (2010). Activity Profile in Elite Italian Soccer Team, *International Journal of Sports Medicine*, 31(5), 304–10.

Wooldridge JF (2012). *Introductory Econometrics - A Modern Approach*, 3rd ed., South-Western, Cengage Learning.

World Health Organization (2010), *Global Recommendations on Physical Activity for Health*, Switzerland: WHO Press.

Zwiers R, Zantvoord FW, Engelaer FM, van Bodegom D, van der Ouderaa FJG, Westendorp GJ (2012). Mortality in former Olympic athletes: retrospective cohort analysis, *British Medical Journal*, 345: e7456.

Statistical database:

Data from First Division (Liga BBVA), Second Division (Liga Adelante), Second B and Spain National Team. Available at: https://www.bdfutbol.com/ . Last accessed: August 2018.

European National Football Teams matches database. Available at: https://eu-football.info/ . Last accessed: August 2018.

Federação Portuguesa de Futebol. Available at: https://www.fpf.pt/Jogadores . Last accessed: August 2018.

National Football Teams. Available at: https://www.national-football-teams.com/ . Last accessed: August 2018.

Real Federación Española de Fútbol. Available at: http://www.sefutbol.com/jugadores . Last accessed: August 2018.

Shkolnikov, V., Barbieri, M. and Wilmoth, J. (2018). Human Mortality Database. Available at: https://www.mortality.org/ . Last accessed: August 2018.

Zerozero.pt. Available at: https://www.zerozero.pt/jogadores.php . Last accessed: August 2018.